NASA Conference Publication 2438

1986 Get Away Special Experimenter's Symposium

Proceedings of a symposium held at
NASA Goddard Space Flight Center
Greenbelt, Maryland
October 7-8, 1986

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1986 Get Away Special Experimenter's Symposium

Edited by
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NASA Goddard Space Flight Center
Greenbelt, Maryland

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Tracking the GLOMR Satellite

by

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Defense Systems, Inc. (DSI), McLean, Virginia

Abstract

The task of day-to-day low orbiting satellite tracking utilizing the NAVSPASUR orbital elements is discussed and methods for improving pass time predictions are presented. Estimates are needed for preprogramming of satellite-initiated communications scheduling which requires an accuracy of approximately 30 seconds. This can be achieved by removing the variance associated with the NAVSPASUR D_2 (decay) term. Finally, the "shock" evidenced in GLOMR's orbit on February 7, 1986 is documented and attributed to a severe solar storm with immediately enhanced drag. GLOMR's life expectancy in orbit is now estimated to have dropped approximately 17% with end of orbit in early February, 1987.

Background

STS 61-A lifted off on October 30, 1985, carrying aloft DARPA's GLOMR satellite stowed in its GAS canister fixed in the port section of the cargo bay. It was a flawless launch and the DSI ground control team anxiously awaited the deployment of the 64.5 kg store/forward communications satellite, GLOMR (Global Low Orbiting Message Relay). Just south of the Fox and Shumagin Islands of the Aleutian chain, on Orbit 9, about twelve and a half hours into the mission, GLOMR bolted gracefully from its "can" into a nearly circular orbit some 326 km above the Earth. The 62 faceted nearly spherical object, with its four top-mounted antennae, prompted astronaut Sally Ride to exclaim that it looked like something from Alien or Sesame Street! Finally, on Orbit 17, the craft passed solidly within DSI's McLean, Virginia-based line of sight and we completed our first contact, and thus began the GLOMR mission which was 259 days long on July 17, 1986. Complete details of the DSI GLOMR design, fabrication, certification, and mission are contained in the 1985 GAS Experimenter's Symposium paper titled "The GLOMR Satellite, Payload G-308".

Satellite Tracking and Operations

Once successfully deployed, GLOMR's position has been obtained on a periodic basis from NAVSPASUR "one-line" orbital data elements. Our operating technique often included the requirement to initiate contact with the spacecraft at a predetermined elevation angle and not before, if possible. Additionally, we chose not to carry over the communication into the region of highest rate of Doppler change, and thus limited our contact windows to two intervals on the ascending and descending portion of each significantly elevated pass. To operate successfully in this manner required timing accuracies on the order of about 30 seconds. The Keppler problem was solved using Brown's non-iterative solution together with the J_2 perturbation and a decay term provided as the NAVSPASUR element D_2. Calculational accuracy was maintained at double precision as predictions of satellite positions were converted to terrestrial azimuth and elevation angles and slant ranges according to an ellipsoidal Earth model. With these modest tools, we set out to "track" GLOMR over a long period of time but with projections forward by approximately ten to twenty days. Since GLOMR must initiate contact with the ground control station, it must normally be "programmed" via an uplinked series of communicate orders, i.e., a schedule. Then in accordance with the onboard clock, the internal orders are carried out based on the computed communication windows generated by the orbital model.

Observed Tracking Sensitivities

It was clear that the NAVSPASUR tracking software was unsettled within the first two weeks of operation on GLOMR. No decay term was reported during this interval and some of the orbital parameters exhibited fluctuations (see the orbital eccentricity data of Figure 1 during this period). After the initial settling period, the data elements have maintained consistent quality and characteristics. After two months in orbit, GLOMR exhibited a true period of regression of the line of nodes of 79.15 days (precession of the orbital plane) and a period of elliptic axis (line of apsides) rotation of 190.0 days (in the orbital plane). However, it was learned early on that the D_2 Decay Coefficient reported in radians per Herg squared was a potential problem. Major fluctuations are evident in this term as depicted in Figure 2. An analysis of the sensitivity of the tracking timing error due solely to these fluctuations in December 1985 showed that an error of +/-1 minute could result after 10 days, increasing up to +/-3 minutes in 26 days. If, instead of directly plugging in the NAVSPASUR D_2 term one were to compute the average or "smoothed D_2-Value" and use this instead, tracking error was reduced by 84% (i.e., from -178 seconds down to -29 seconds). It is presumed that the D_2 term is a differentially derived parameter or a filter product that does not well reflect the average steady decline of the orbit. This subject will be revisited below. Given that fluctuations in the NAVSPASUR elements are typical (a presumption based only on the GLOMR observations), then further examination of other sensitivity coefficients was appropriate. Using the February 5, 1986 epoch data as a basis, the following sensitivities were computed using the orbit program:

Orbital Parameter	CPA Timing Error (sec) Unit Parameter Change per Day
Mean Anomaly M_0	-500.0 sec/day/ΔM_0
Mean Motion M_1	-99,161.58 sec/day/ΔM_1
Decay Coefficient D_2	-1,233.33 sec/day/ΔD_2
Eccentricity e_0	+250.0 sec/day/Δe_0
Argument of Perigee ω_0	-468.33 sec/day/$\Delta\omega_0$
Long of Ascending Node λ_0	-233.33 sec/day/$\Delta\lambda_0$
Inclination i_0	+2,500.0 sec/day/Δi_0

The net timing error can be estimated as the sum of products of the above error rates times the average values of the corresponding orbital parameters. Using the most severe fluctuations of all parameters over the entire period of observation, the "worst case" scenario would result in timing errors of about a minute per day. As noted, with the "removal" of the D_2 fluctuation and use of a smoothed value, errors on the order of one second per day are often attained. Nevertheless, attention to the behavior of all the orbital elements is well justified as we shall see next.

Solar Disturbance of February 1986

At low altitudes, satellites face the unescapable force of atmospheric friction. As the altitude declines the orbital altitude decreases and the satellite speeds up in an accelerating death-spiral. As we studied GLOMR's gradual descent we reported a rate of approximately -0.11 km/day throughout the first 100 days of orbit. However, after February 7, 1986, pass timings (communications windows) began to deviate significantly from the earlier predictions used to program the satellite processors. In fact, the orbit seemed to have decayed abruptly with the result that we accumulated an error of approximately -11 sec/day. Due both to the pre-scheduling of the GLOMR contacts and to the day late arrival of the NAVSPASUR Charlie Elements, the immediate cause of the shift was unclear. Once the NAVSPASUR data became available, it appeared that a substantial "shock" occurred on February 7th (day 99 on the various graphs). Sudden enhancement of the atmospheric density at this time buffeted GLOMR and induced immediate "ringing" of the NAVSPASUR tracking filters as evidenced in the eccentricity (Figure 1) and the sharp upward jump of the decay term as shown in Figure 2. But by far more significant, yet not obvious to the casual observer, was the ramp in the mean motion curve. Using the equivalent mean altitude as depicted in Figure 3, three features are observable:

(1) The small dip on day 87 (January 26, 1986);
(2) A second dip peaked at day 104 (February 12, 1986);
(3) A sharp slope change at day 99 (February 7, 1986).

The first dip is not real since the altitude immediately recovers and follows the well established straight line behavior with a rate of -0.411 nmi/week prior to the disturbance which certainly occurred on the 7th of February. The second dip is probably NAVSPASUR tracker response to the immediate change in the derivative of the mean motion parameter. This is real since from this point on the orbit is now again on a "straight line" descent with a rate of -0.5946 nmi/week. This represents a -44.7% change in the rate of descent and clearly will affect the GLOMR mission lifetime.

Other evidence includes the decay term D_2 of Figure 2, which shows two average line fits one before and one after the disturbance:

	Smoothed Decay Term	Standard Deviation
Before:	0.01036	0.001356
After:	0.01482 (43% increase)	0.002381 (76% increase)

The 43% increase in the decay term matches the 44% drop in the rate of descent noted above since the rate of descent is approximately related to the decay term as:

$$da/dt = -(4/3)E-5 * D_2 * a^{2.5}$$

where a is the semi-major axis. Using the pre-disturbance D_2 -value (smooth) of 0.10362, the computed rate of change of altitude is -0.402 nmi/week which agrees with the curve fit value of -0.411 reported above. Likewise, the post-disturbance value is computed to be -0.5755 nmi/week which compares nicely with the previous value of -0.5946. At least in terms of "smoothed" D_2-values, there is agreement between the orbital parameters and the documented observances. It is suggested that a "long-term" fit to the rate of descent curve to get da/dt (nmi/wk) inserted into the following equation will produce an optimum smooth D_2-value:

$$D_2 \text{ (smooth)} = 0.029051 * (da/dt) * [(3444 + ALT)/3444]^{-2.5}$$

In this expression ALT is the current mean altitude in nmi. The approximation presumes a nearly circular orbit.

NAVSPASUR reported to us that the storm was the worst in its history and that the Geomagnetic Index (which had been in the 30-40 range) jumped to 89, 236, and 98 for February 7, 8, and 9, respectively. Further evidence included a jump in the Exospheric Temperature from the 700s up to 997, 1164, and 1001. Now that the storm effects on the orbital parameters were established, the ramifications to GLOMR's lifetime were explored.

GLOMR Orbital Life Expectancy

Assuming a nearly circular orbit and further that 145 km marks the essential "terminal" altitude, the orbital lifetime is approximated by:

$$L = -\int_{ALT_0}^{145\text{ km}} \frac{d(ALT)}{(C_d * A/m) * \rho(ALT) * (M*G*ALT)^{-0.5}}$$

where M is the mass of the Earth, G is the Universal Gravitation Coefficient, m is the satellite mass (64.5 kg), A is the satellite projected area (0.162 m^2), C_d is the drag coefficient, and ρ is the atmospheric density. The CIRA 1972 Mean Reference Atmosphere was used (see Figure 4) via curve fit in the 90 to 400 km regime:

$$\log \rho(\mathrm{kg/m^3}) = -8.384 * (1+\mathrm{ALT} * 9.079795\mathrm{E}{-4}) * (1-(67.75/\mathrm{ALT})^3)$$

ALT is expressed in km. The lifetime integral L was evaluated for the two situations: before and after the large storm of February, 1986. Figure 5 presents these results. The drag coefficient was empirically fitted to data in the two regimes so that the altitude dynamic matched the computed values. The use of an emperical value also allows for the fact that the orbit is slightly eccentric. The before and after values for C_d are, respectively, 0.43455 and 0.52513. If C_d is approximately constant, then this is equivalent to an increase of 21% in atmospheric density. GLOMR's lifetime has thus been reduced by about 17.3% and, according to the model, should fall to Earth 365 days past the date of the storm or about February 7, 1987. This assumes no further change in drag between the GLOMR altitude of 290 km on July 17, 1986 and the 145 km value which should occur six months from now.

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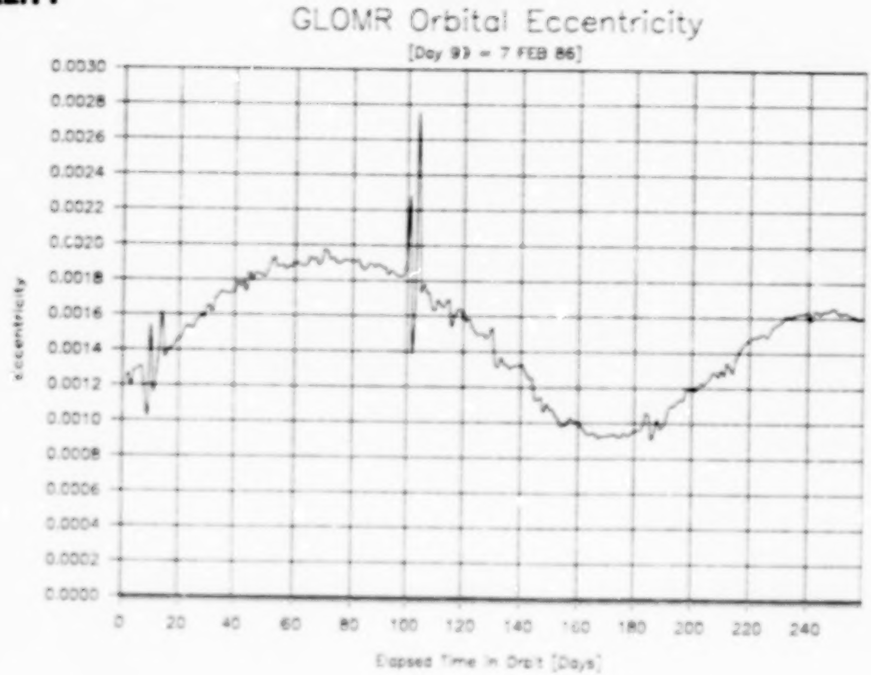

FIGURE 1

LONG TERM BEHAVIOR OF THE GLOMR ORBITAL ECCENTRICITY

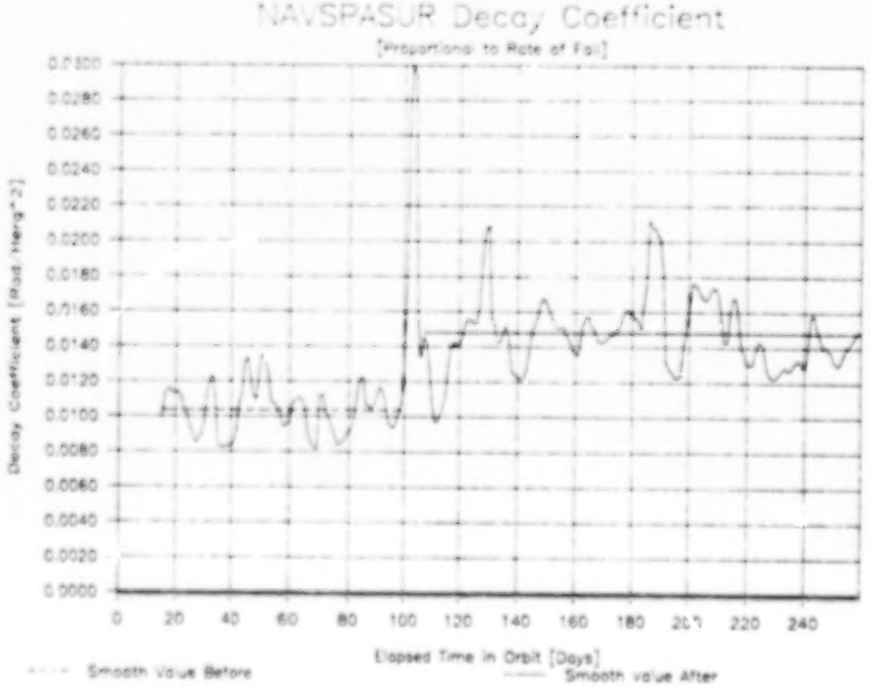

FIGURE 2

NAVSPASUR D_2 DECAY COEFFICIENT WITH SUPERIMPOSED LMS LINE FITTED BEFORE AND AFTER THE SOLAR STORM

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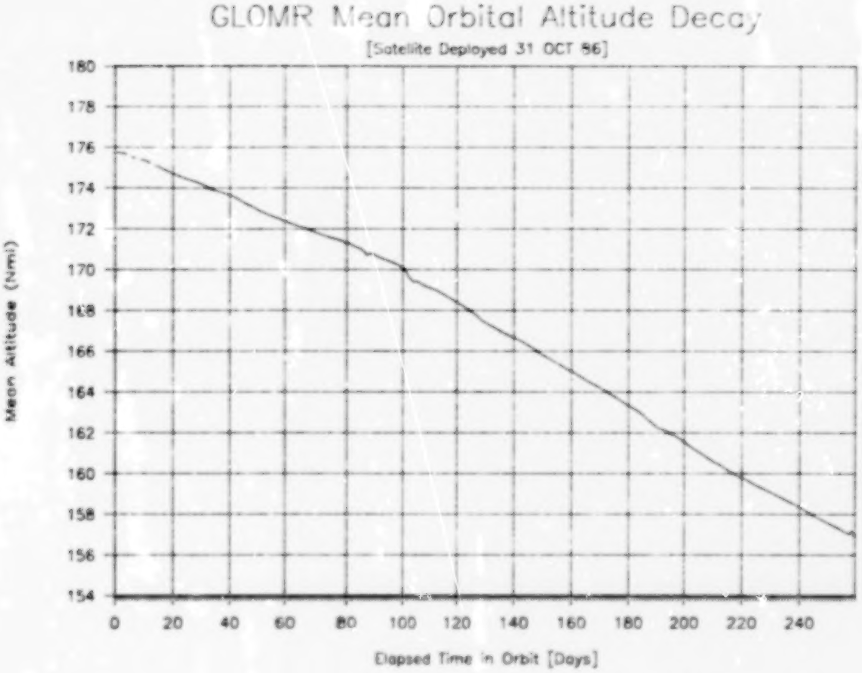

FIGURE 3

GLOMR'S DESCENT IS CHARTED HERE. THE SLOPE CHANGE AT DAY 99 CAN EASILY BE SEEN WITH A RULER: INITIAL RATE =-0.411 NMI/WEEK WITH A VALUE OF -0.5946 NMI/WEEK AFTER THE DISTURBANCE ON THAT DATE.

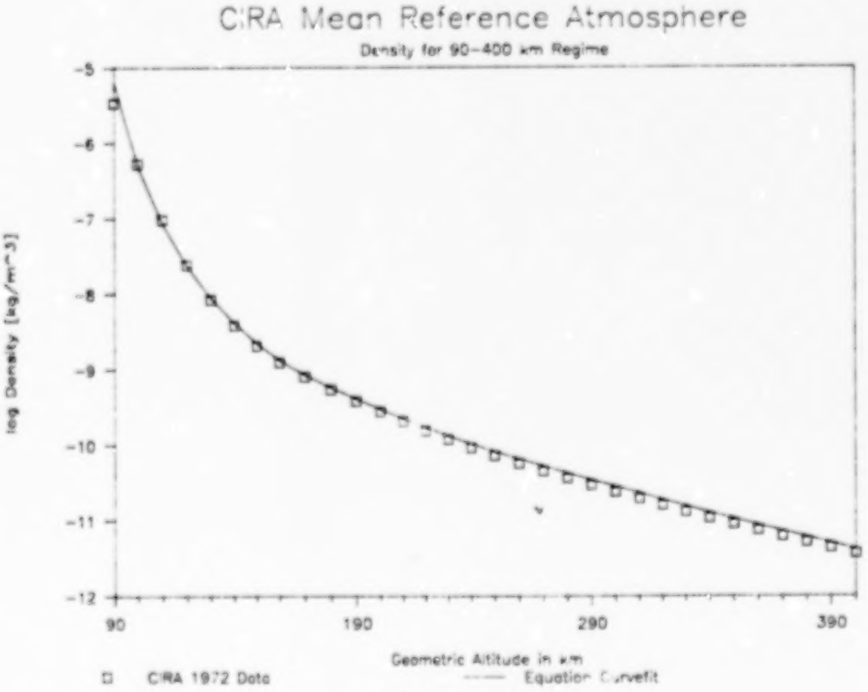

FIGURE 4

COSPAR INTERNATIONAL REFERENCE ATMOSPHERE (CIRA) 1972 ATMOSPHERIC DENSITY IN THE GLOMR OPERATIONAL REGIME WITH EMPERICAL FUNCTIONAL CURVEFIT USED IN GLOMR ORBITAL LIFETIME MODEL.

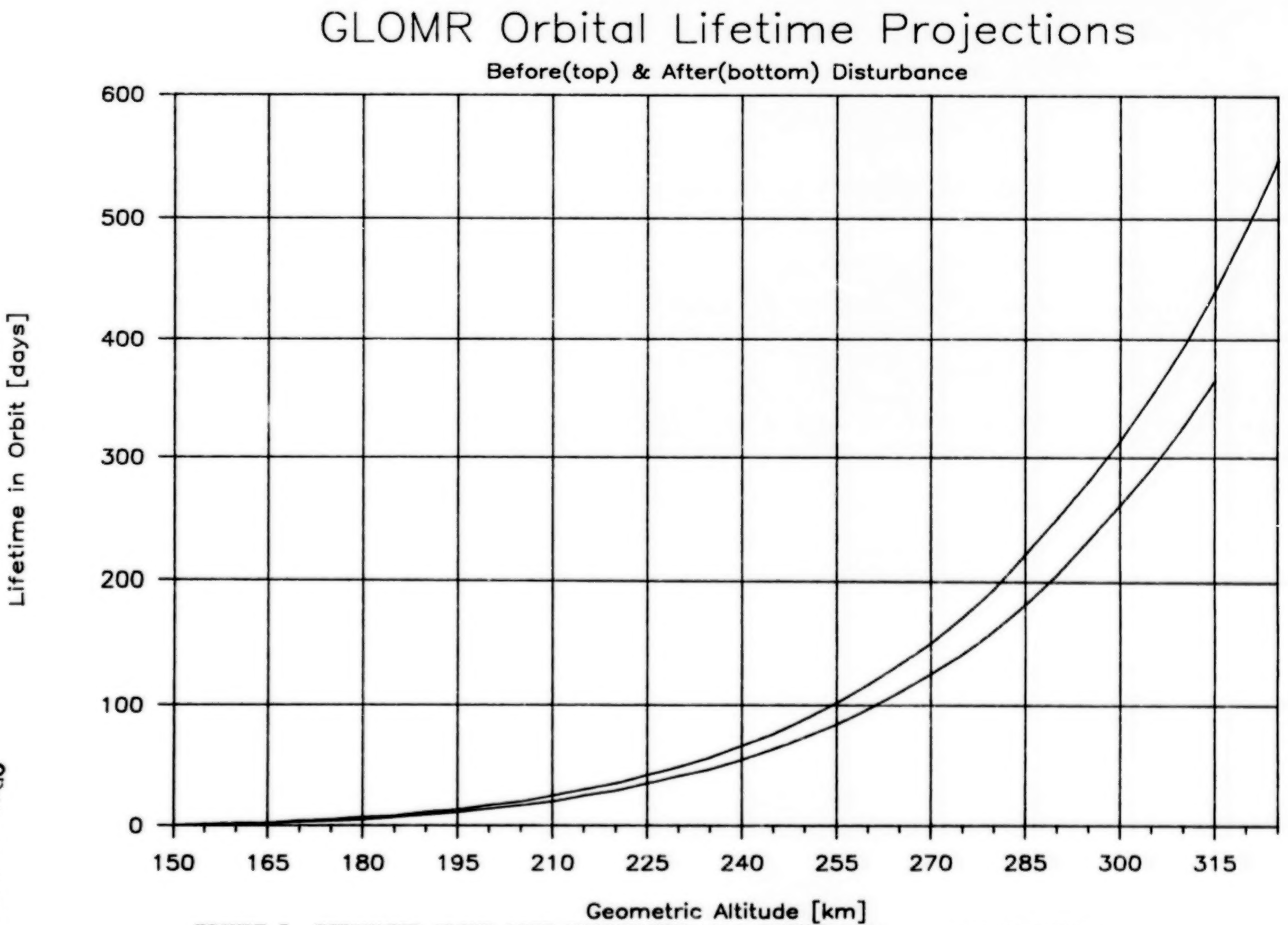

FIGURE 5 ESTIMATED GLOMR LIFE EXPECTANCY AS A FUNCTION OF [illegible] ALTITUDE BEFORE (TOP CURVE) AND AFTER (BOTTOM CURVE) THE SEVERE SOLAR STORM OBSERVED ON FEBRUARY 7, 1986.

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MANUFACTURING POLYMER THIN FILMS
IN A MICRO-GRAVITY ENVIRONMENT

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ABSTRACT

This project represents Venezuela's first scientific experiment in space.

The apparatus for the automatic casting of two polymer thin films will be contained in NASA's Payload No. G-559 of the Get Away Special program for a future orbital space flight in the U.S. Space Shuttle.

Semi-permeable polymer membranes have important applications in a variety of fields, such as medicine, energy, and pharmaceuticals and in general fluid separation processes, such as reverse osmosis, ultrafiltration, and electrodialysis.

The casting of semi-permeable membranes in space will help to identify the roles of convection in determining the structure of these membranes.

INTRODUCTION

The idea of casting semi-permeable polymer membranes in a microgravity environment was developed by the author in 1984 after experimental evidence showed that the morphological structure of these synthetic membranes is affected by convection forces.

The Get Away Special program was selected after several weeks of learning and understanding the NASA procedures and opportunities available to scientists wishing to do space experimentation. It was recognized that this program would require an automatic system to be developed for the performance of the experiment.

Special design considerations were taken in order to ensure the construction of an apparatus which could successfully handle the fluids involved in this experiment.

JUSTIFICATION

The formation of porous membranes by the coagulation of a polymer solution in a non-solvent bath (phase inversion technique) has been studied intensively in the last few years. Despite the great advances in membrane technology and its applications, there is a need to improve the fundamental understanding of the mechanism governing membrane formation and its structure.

This proposed research is based on reported phenomena concerning the specific gravity contribution to the molecular morphology of polymer membranes.

In at least two steps (evaporation step and gelation step) of the Phase Inversion Casting Mechanism, the differences in specific gravity between the cast polymer solution and the coagulating liquid affect the entire structure of the polymer films.

During the evaporation step the removal of the solvent breaks the thermo-dynamic equilibrium of the polymer structure. When the process is dominated by convection forces, the violent movement of polymer aggregates and hence their coalescence causes the formation of large voids or imperfections (Figure 1).[1]

During the gelation step the convection flows of solvent and solvent non-solvent mixtures through the cast layer interface prevail concurrently with the diffusive exchange of solvent with non-solvent. When the differences in specific gravity are high, the coagulation is controlled by convection rather than diffusion and dense, tight semi-isotropic membranes are formed (Figure 2). The structure of these membranes are far from the ideal anisotropic porous structure (Figure 3).[2]

By casting the membranes in a micro-gravity environment, the effect of convection upon these polymer films can be identified. Furthermore, membranes with a better morphological structure and membranes with fewer imperfections might be produced.[3]

EXPERIMENT DESCRIPTION

A schematic of the experiment concept is presented in Figure 4, along with the desired sequence. The experiment will be conducted in one-half of a 5 cubic-foot cylinder, as shown in Figure 5.

An apparatus for the automatic casting of two polymer films of different chemical compositions has been designed. The casting will be performed simultaneously and will be followed by flushing with cold water.

The payload has an active heating subsystem. The plan to maintain the temperature between the limits of 0°C and 30°C is to allow the ambient thermal conditions in the Orbiter bay to drive the temperature down to near 0°C passively. If the temperature reaches this low level, a thermo-stat will activate strip heaters to elevate the temperature to values between 10°C and 20°C.

The membrane casting apparatus will be contained in NASA's payload No. G-559 of the Get Away Special program for a future flight in the U.S. Space Shuttle. This payload will also contain a protein crystal growth experiment and a cell growth experiment, both being developed by the Bioprocessing and Pharmaceutical Research Center of the Philadelphia University City Science Center.

The whole system with the experiments, structure, and avionics will be subjected to acceleration, vibration, and thermal-vacuum tests replicating launch and space conditions.

EXPERIMENTAL METHODOLOGY

The conditions for the casting of polymer membranes in a microgravity environment will replicate as closely as possible the conditions under which polymer membranes are produced on earth (i.e. pressure, temperature, humidity, etc.) All of these conditions will be recorded in space.

Once on earth, the membranes cast in space will be tested in three general areas:

Transport Ability: Reverse Osmosis, Dialysis, Ultrafiltration;
Mechanical Testing: Young Modulus, Collapse Pressure; and
Morphology Analysis: Scanning Electron Microscope, Wet test,dry test.

PROGRESS

This project was initiated at the end of 1984 with the support of the Venezuelan Government through the National Electric Company of Venezuela.

The design phase and safety analysis have been completed. Fabrication, testing, and integration of the prototype unit and of the prime flight hardware are expected to be completed by the end of 1986.

CONSULTATIONS

Throughout the development of this project, several scientific institutions have offered their guidance, advice, and encouragement. They include:

1. The Bioprocessing and Pharmaceutical Research Center of the U.C.S.C. of Philadelphia;
2. The Polymer Research Institute of the State University of New York;
3. The Chemistry Department of the National Research Council of Canada;
4. The Energy Center and the Chemical Engineering Deparment of the University of Pennsylvania.

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FIGURES

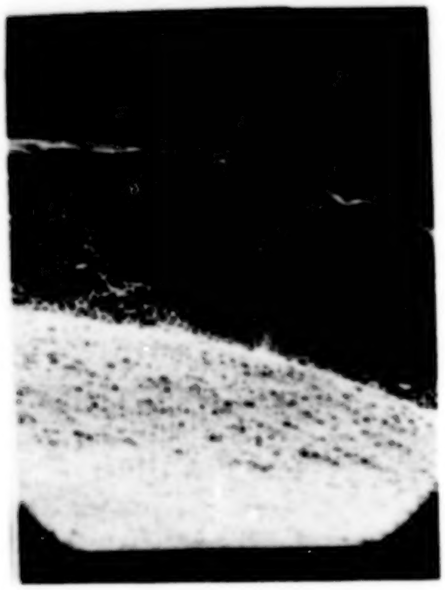

FIGURE 1. Micrograph of Cross-Section of a Polymer Membrane Exhibiting a Macrovoid (SEM - 800 mag.)

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FIGURE 2. Micrograph of Cross-Section of a Dense Semi-Isotropic Polymer Membrane (SEM - 2500 mag.)

FIGURE 3. Micrograph of Cross-Section of a Porous Anisotropic Polymer Membrane (SEM _ 1400 mag.)

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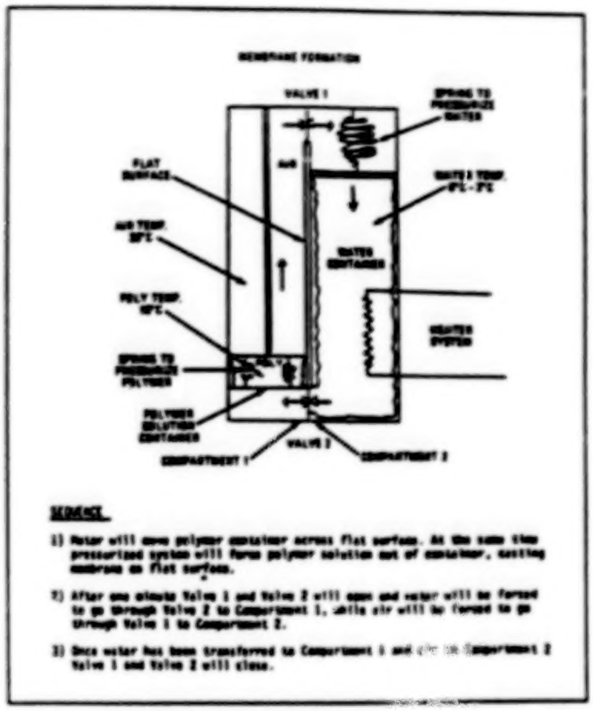

SEQUENCE

1) Motor will move polymer container across flat surface. At the same time pressurized system will force polymer solution out of container, casting membrane on flat surface.

2) After one minute Valve 1 and Valve 2 will open and water will be forced to go through Valve 2 to Compartment 1, while air will be forced to go through Valve 1 to Compartment 2.

3) Once water has been transferred to Compartment 1 and air to Compartment 2 Valve 1 and Valve 2 will close.

FIGURE 4. Experiment Concept

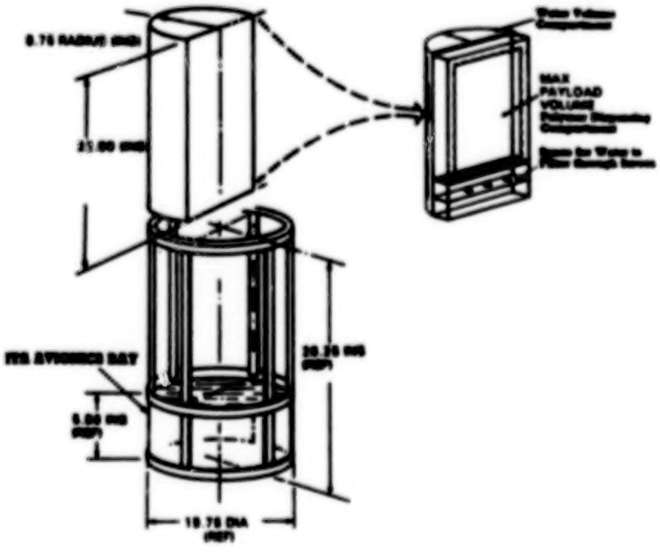

FIGURE 5. Longitudinal Cylinder

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PHASE PARTITIONING, CRYSTAL GROWTH, ELECTRODEPOSITION AND COSMIC RAY EXPERIMENTS IN MICROGRAVITY

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NASA GODDARD SPACE FLIGHT CENTER
OCTOBER 7-8, 1986

ABSTRACT

Five experiments are contained in one GetAway Special Canister (5 ft^3). The first utilizes microgravity to separate biological cells and to study the mechanism of phase partitioning in 12 separate cuvettes. Two experiments are designed to grow organic crystals by physical vapor transport. One experiment consists of eight electroplating cells with various chemicals to produce surfaces electroplated in microgravity. Some of the surfaces have micron sized particles of hard materials co-deposited during electrodeposition. The fifth experiment intercepts cosmic ray particles and records their paths on photographic emulsions. The first four experiments are controlled by an on-board C-MOS controller. The fifth experiment is totally passive. These are the first of a series of experiments planned by the Consortium for Materials Development in Space. Their purpose is to create new commercial products with microgravity processing.

INTRODUCTION

The GAS Experiment package consists of five experiments. Four utilize the microgravity of space flight and one is a cosmic ray experiment. The experiments are: Separation of Aqueous Phases, J. M. Harris principal investigator (P.I.) cooperating with Celanese Research Corporation; Polymer Crystallization, S. P. McManus, P.I. cooperating with General Telephone and Electronics; Monomeric Crystallization, J. M. Harris, P.I. cooperating with Celanese Research Corporation; Electrodeposition and Co-deposition, H. D. Coble, C. Riley and Br[illegible] Loo co-P.I. cooperating with McDonnell Douglas Astronautics Company-Huntsvill and Cosmic Ray studies, J. C. Gregory, P.I. The Marshall Amateur Radio Club has prepared an electronics package to support the experiments thereby providing power, control, and a data system. Graduate and undergraduate students participate in the design and testing of the apparatus.

SEPARATION OF AQUEOUS PHASES (SOAP)

When aqueous solutions of pairs of certain neutral polymers (such as dextran and polyethylene glycol) are mixed above certain concentrations, systems composed of two immiscible phases are formed. If an impure biological material is added to such a system, and the system shaken, the biomaterial will, upon re-equilibration, partition between the two phases or, in the case of cells, between one of the phases and the interface between the phases. This simple phase partitioning process has been applied as a very important purification technique of considerable biotechnological importance.

Gravity plays a major role in phase partitioning. Not only does gravity degrade separations via the slow sedimentation of cells, but it also affects partition by controlling the rate of phase separation and the resulting fluid convection.

The SOAP equipment consists of a set of small cube shaped glass cuvettes (approx. 1.5 ml) with a magnetic stirring bar inside and a small stirring motor on top. These stirred cuvettes are monitored by means of 35 mm photography.

A set of twelve cuvettes are mounted in a temperature controlled, insulated aluminum block. See figure 1. The back of the block contains a frosted glass window through which a strobe light flashes for back lighting the cuvettes. The front of the block contains a clear piece of glass for an unobstructed view of the cuvettes. The glass has an infrared reflective coating to decrease radiation heat loss from the cuvettes. A nichrome wire spans the space between the cells and acts as a resistance heater. The temperature is sensed by the controller via a thermistor in the block; the controller regulates power to the nichrome wire. Insulated covers enclose the remainder of the block.

The object of this microgravity experiment is to study the rate of phase separation in low G and determine means by which the rate may be controlled. This study builds on a previous UAH shuttle flight (STS 51D) in which preliminary experiments were performed. It appears that wall coatings can be used to accelerate and control phase separation. This first flight tests this tentative conclusion. Coatings are applied to some of the glass cuvettes and stirring bars.

The actual performance of the experiment is simple. The device is designed so that upon activation by the G #105 on board controller, the two immiscible liquids are stirred for 20 seconds (as determined by testing). Then the stirring stops and photography begins. Photographs are taken every 30 seconds for four minutes followed by photographs every 10 minutes for two hours; a final photograph is taken at 10 hours. These photographs will later be analyzed with an optical densitometer.

POLYMER CRYSTALLIZATION

Crystals of a monomeric organic substance are grown by vapor phase deposition. The experimental compartment consists of a series of quartz reaction cylinders. See Figure 2. A fritted glass disk in the center of each of the cylinders divides the chambers and physically retains the uncrystallized material in one end of the cell. The cylinders are under high vacuum and the fill tube is removed for flight. The material to be vapor deposited is coated on glass honeycomb in one end of the cell, which has a resistance heater wound around it. At the other end of the cylinder a seed crystal of the material is mounted. That end is fitted with a thermoelectric cooling device. Temperature monitors are fitted at the two ends of each tube. A thermocontroller portion of the on-board controller is utilized to control the temperatures.

When the experiment is turned "on" by the G #105 on-board controller, a signal is given the thermocontroller to control the cell temperature containing the monomeric material at about 80 degrees C. At the same time, the thermocontroller controls (by cooling) the end of the cell containing the seed crystal so that its temperature is 80 degrees C lower than that of the heated end of the tube. When both ends are at their target temperatures, vapor or organic material will pass from the heated cell to the cooled cell and crystallize on the seed crystal resulting in the growth of a large single crystal. After an appropriate growth period, presently estimated at 16 hours (time to be established in ground-based experiments by GTE) the thermoregulator will be instructed to cease cooling and heating the device.

The resulting crystals, to be collected, polymerized and analyzed after the GAS can is opened are of a type which have great promise for application in a new generation of high speed computers and in the communications industry.

MONOMER CRYSTALLIZATION

In this monomeric crystallization experiment (MCE) organic crystals are grown by vapor deposition. The organic materials are provided by Celanese Corporation and are of great interest as nonlinear optical materials. It is expected that the absence of concentration driven convection at the face of a growing crystal results in growth of more highly ordered and possibly larger crystals. Previous experiments have shown that improved crystal size and quality is achieved in microgravity. This experiment builds on previous experience to grow more highly ordered and larger organic crystals for optical applications. After crystals are recovered they will be evaluated by Celanese and by the Materials Sciences Laboratory at UAH.

The experimental compartment consists of an evacuated quartz tube, similar to that used in the polymer crystallization experiment. See Figure 3. Again, the fill tube is removed before flight. The entire tube is wrapped with resistance heating coils. The tube end containing the material to be vapor deposited is heated to within 3-5 degrees (T_1) of the melting point (T_m) while the deposition end (containing a seed crystal on a glass flat) is heated to T_2 (to within 2-5 degrees of T_1). Thus,

$$T_1 - T_2 = 2\text{-}5° \text{ C}$$

$$T_m - T_1 = 3\text{-}5° \text{ C}$$

Two materials are under consideration having T_m values of 133 and 90° C. These melting points define the temperature requirements of the apparatus. Temperatures are measured during the experiments by thermistors at both ends of the tube and in the middle. These temperatures are stored and controlled as a function of time during the experiment by the on-board computer.

The time required for the experiment is approximately 24 hours depending on the temperature difference and material chosen. When the experiment is turned on by the G #105 on board controller the tube containing the material to be vapor deposited is heated to T_1 while the other end of the tube is heated to T_2. Vapor of the material passes to the cooler end where it crystallizes on the seed crystal resulting in the growth of a large single crystal. After an appropriate growth period the experiment is turned off and the crystals returned to earth for evaluation.

ELECTRODEPOSITION AND CO-DEPOSITION

Electrodeposition and co-deposition of materials are commercially important processes which can produce superior products under low gravity conditions because electromechanical processes are significantly influenced by gravity. The objective of this experiment is to understand gravity's role in simple metal electrodeposition and co-deposition for the purpose of producing commercial products in space. Surface coating processes to be developed for application in industrial operations are: 1) coatings for producing crystal morphologies with catalytic properties significantly greater than that of metal catalysts produced on Earth; 2) coatings that maximize wear-resistance, antifriction and anti-seizing properties.

During electrodeposition in a gravity environment, density gradients are created which result in convective transport that affects forming and surface preparations. Similarly, in co-depositions, particles in neutral suspensions tend to sediment, causing inhomogeneous coatings and reductions in the volume fraction of the occluded neutral. The microgravity available in Earth orbit provides the environment needed to develop electromechanical processes producing more homogeneous commercial products.

Catalytic activity is related to the size of the catalyst particles and their particular morphologies. The crystallite morphologies in face-centered cubic metals appear to offer the best promise of increased catalytic activity for certain chemical reactions. The higher the deposition potential, the finer the crystalline deposit; thus, a product with high catalytic activity results. In low gravity, the suppression of gravity driven convection will allow the electrodeposition of more powdery, dendritic and twinned deposits, and hence, more active catalysts than are possible on the ground.

We are studying the electrodeposition of materials in space, using eight electrodeposition cells per flight. See Figure 4, and also refer in this volume to a companion paper entitled "Microgravity Effects on Electrodeposition of Metals and Metal Cement Mixtures" by Maybee, Riley, Coble. Metals which may have commercial applications as catalysts include: platinum, palladium, gold, silver, iron and cobalt. We are also testing the feasibility of electrodepositing a metal and a refractory (cobalt-Cr_3C_2)in the low gravity environment of space. The cells (See Figure 5) contain solutions of soluble salts of the metal ions to be deposited. Some of the cells contain micron size particles of chromium carbide or diamond dust. Each cell is energized with a voltage source, each cell drawing approximately 20 milliamps or less of current for up to six hours. The cells, along with their milliammeters are photographed during electroplating. A digital thermometer displays the temperature next to the cells and one cell's voltage will be monitored. These too are photographed.

When the experiment is turned on by the G #105 on-board controller, the two upper co-depositing cells are stirred. After five minutes, the voltage is applied to the electrodes in the cells. Photographs are taken at selected time intervals for six hours. The controller regulates the temperature to a minimum of 25° C during the experiment and to a minimum of 5° C before and after the experiment to prevent freezing. The controller records the temperature, current and voltage and initiates the camera and flash photography. The electrodes are then analyzed and tested upon return to earth.

COSMIC RAY DETERMINATION

Photographic emulsions have been used for 50 years for cosmic ray and particle physics research. It is expected that large emulsion calorimeters will be flown on the Shuttle or Space Station to develop further these areas of high energy physics which UAH and Japanese American Cooperative Emulsion experiment collaboration have recently pioneered.

Fine tuning of the design of these multi-element passive detectors requires a realistic determination of the particle background induced in a massive calorimeter detector. A small emulsion calorimeter, approximately 15 cm by 15 cm is to be flown in the UAH GAS-can to provide this assessment. This experiment also determines materials suitable for marking nuclear tracks.

The emulsion chamber instrument of the type proposed here is totally passive, and consists of approximately 150 thin plates of material, each 6 inches x 6 inches, assembled in a stack 6 inches high. The stack of precision machined plates is mounted in a rigid, lightweight box. The material of the plates includes: silver bromide gel, polymethyl methacrylate (lucite), polycarbonate resin (CR-39), x-ray film, and lead or tungsten plates. These materials are hermetically sealed in the emulsion chamber box, which is placed in the GAS-can so that there is minimum shielding between it and space. The photographic emulsions will be analyzed for nuclear markings upon return to earth.

ACKNOWLEDGEMENT

The author gratefully acknowledges the support of the National Aeronautics and Space Administration Office of Commercial Programs which is funding the Consortium. He also appreciates the close cooperation of the principal investigators in working together to fit all of the experiments within the space and weight limitations of the GAS Can. The design and construction of the controller was by the Marshall Amateur Radio Club, in particular by Mr. Chris Rupp. Cooperation between the Alabama Space and Rocket Center and The University of Alabama in Huntsville continues on G #105 as it did on G #007.

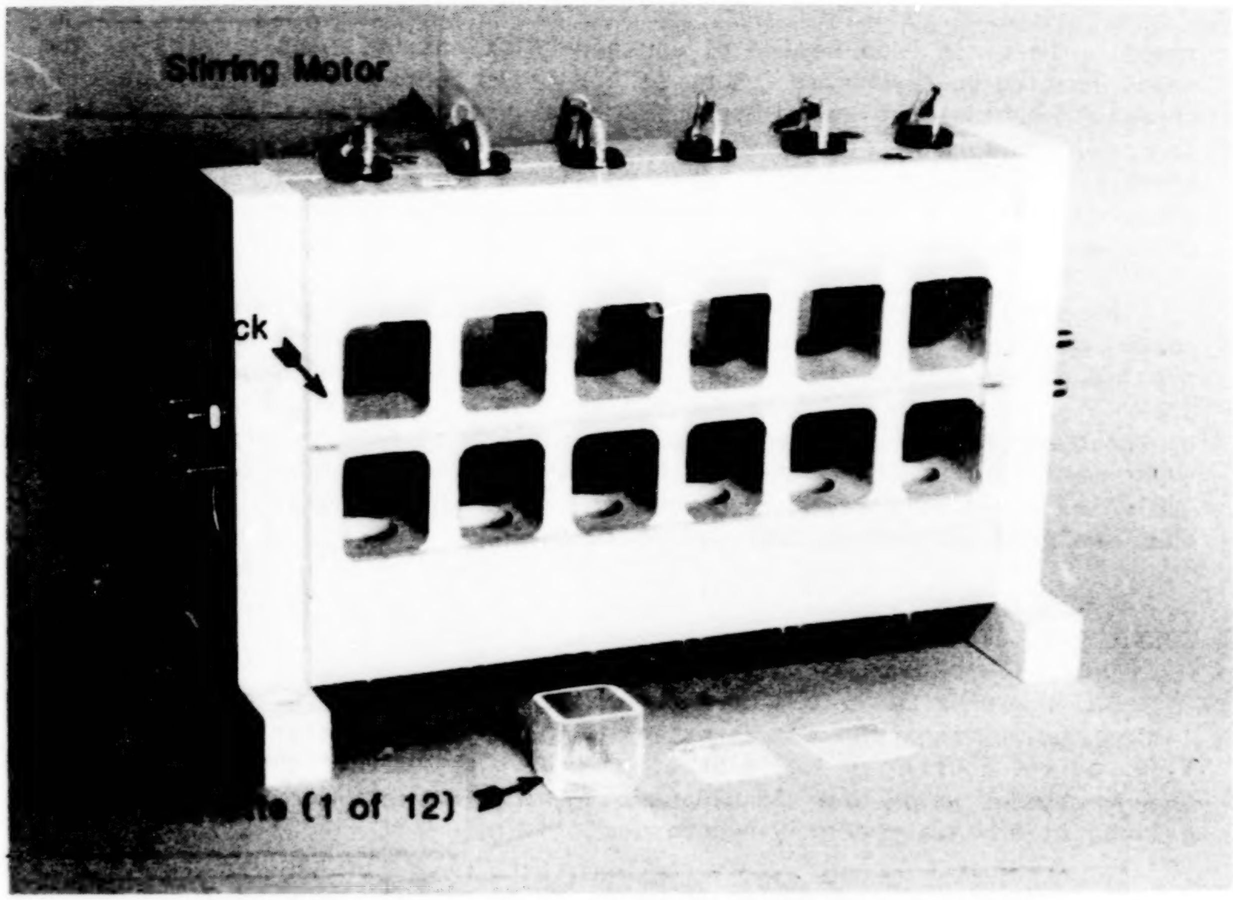

Figure 1 Separation of Aqueous Phases Apparatus

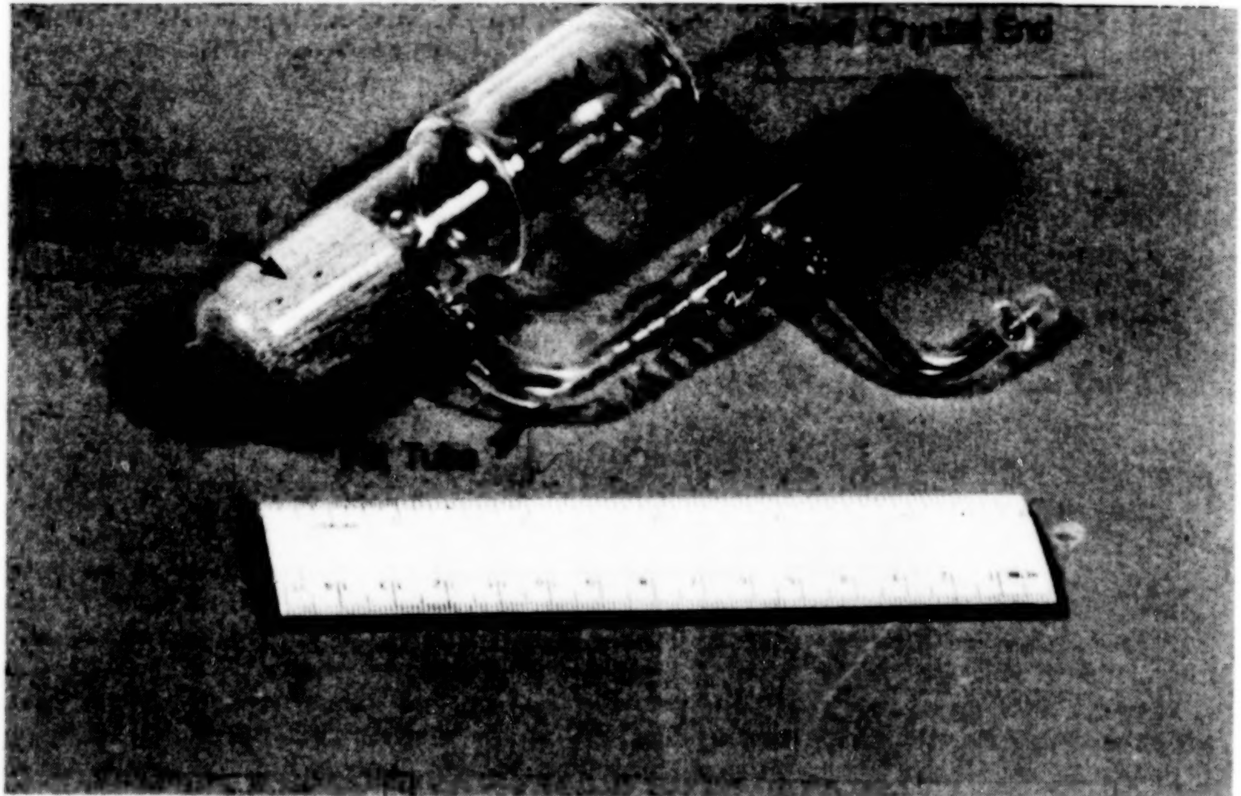

Figure 2 Polymer Crystallization Growth Chamber

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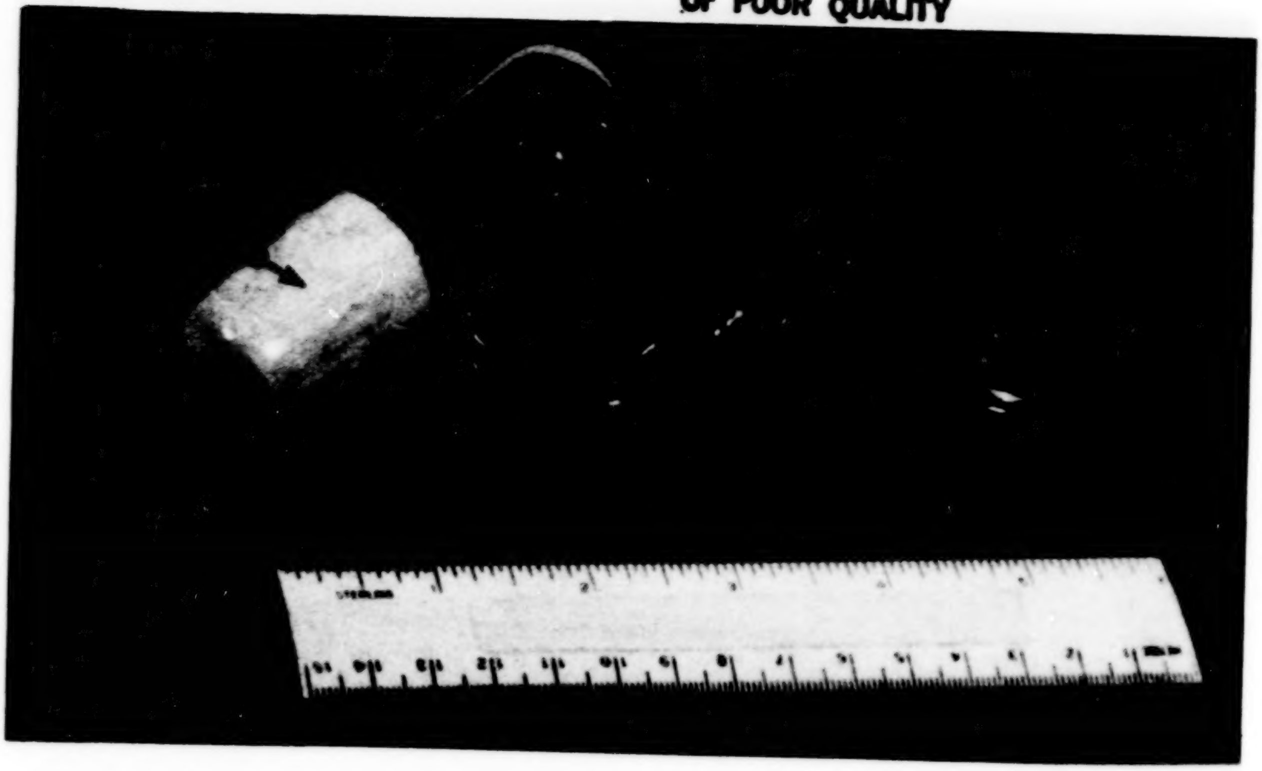

Figure 3 Monomer Crystallization Growth Chamber

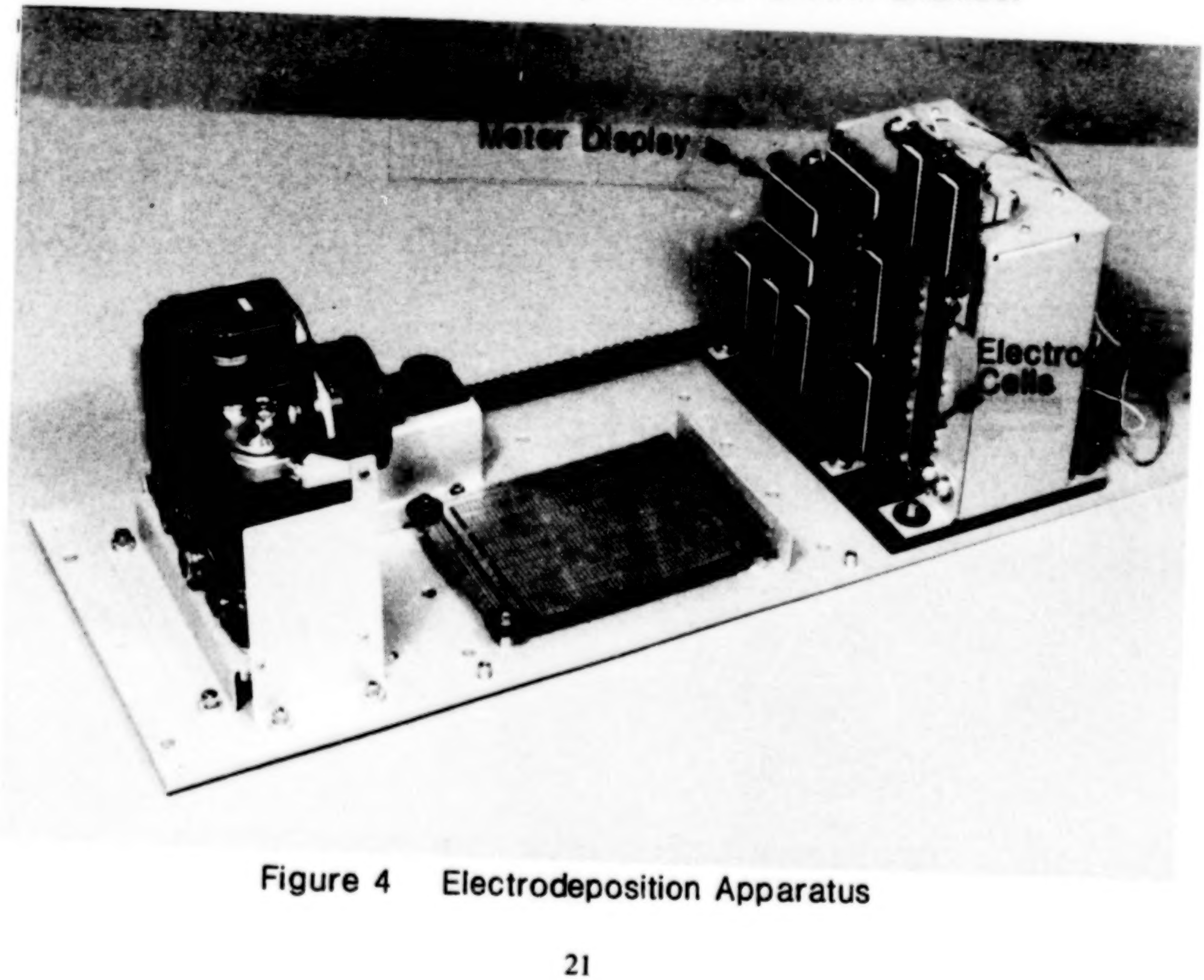

Figure 4 Electrodeposition Apparatus

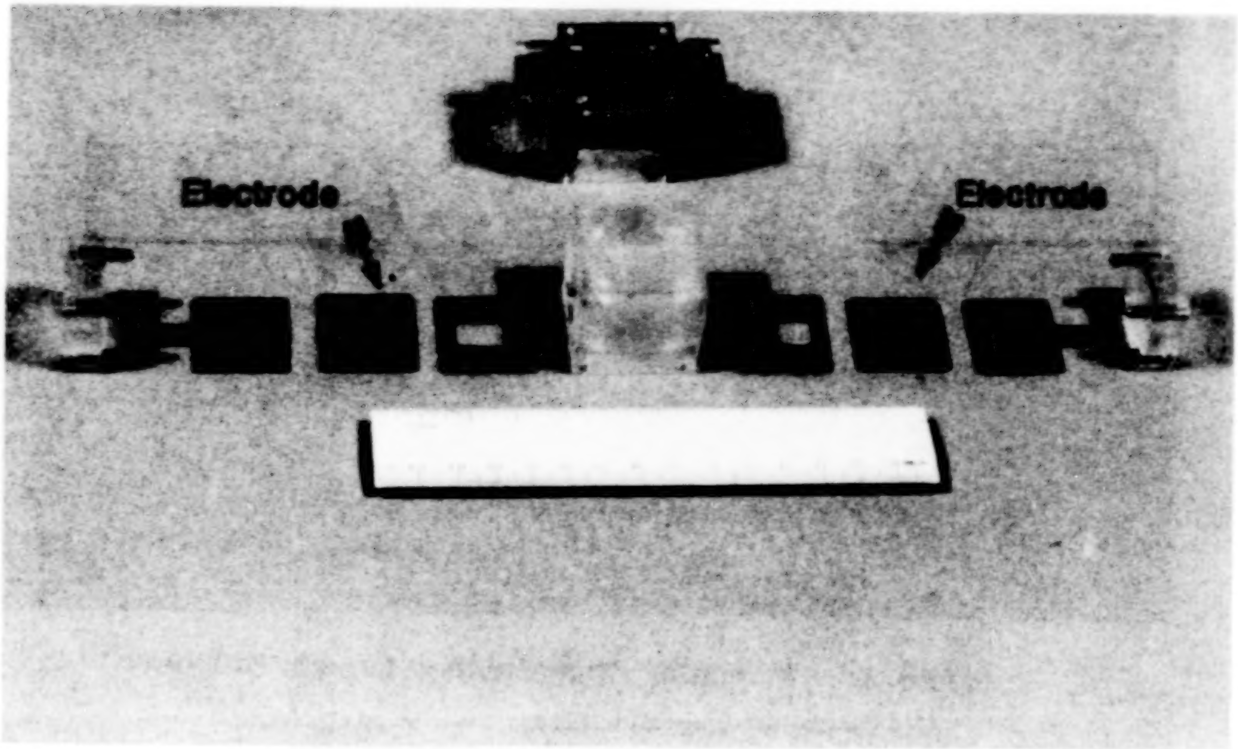

Figure 5 Electrodeposition Cell

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GAS TUNGSTEN ARC WELDING IN A MICROGRAVITY ENVIRONMENT

WORK DONE ON GAS PAYLOAD G-169

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ABSTRACT

In this paper the work done on GAS payload G-169 is discussed. G-169 contains a computer-controlled Gas Tungsten Arc Welder. The equipment design, problem analysis, and problem solutions are presented. Analysis of data gathered from other microgravity arc welding and terrestrial Gas Tungsten Arc Welding (GTAW) experiments are discussed in relation to the predicted results for the GTAW to be performed in microgravity with payload G-169.

OBJECTIVE

The objective of GAS payload G-169 is to provide information on the feasibility of Gas Tungsten Arc Welding (GTAW) in a microgravity environment. A thorough analysis of the weld produced by the payload in space will be done and compared to terrestrial welds produced with the same apparatus. To date GTAW has not been performed in space. The data received from G-169 should have particular significance for the assembly of the space station power system tubing.

The material to be welded is stainless steel 316 L (low carbon). The specimen is a tube 2.00 in. in diameter with a wall thickness of 0.0625 in. A bead on plate weld will be performed.

EXPERIMENTAL DESCRIPTION

As many of the experimental components as possible are off the shelf, commercially produced products. Using off the shelf products shortens the payload design time and ensures reliability.

Payload G-169, shown in Fig. 1, consists of: an experimental mounting rack, a GTAW power supply, a GTAW orbital weld head, a dc to ac power inverter, a pressure vessel of inert gas, a sealed battery box, a battery pack and a payload controller.

EXPERIMENTAL MOUNTING RACK

The experimental mounting rack consists of four shelves, 19.75 in. in diameter. Two of the shelves are 0.250 in. thick and two are 0.125 in. thick. Six, 0.375 inch diameter rods are used for support. Tubing, 0.500 in. diameter, is compression fit between the shelves for spacing and support. All parts of the rack are made of 6061-T6 Aluminum.

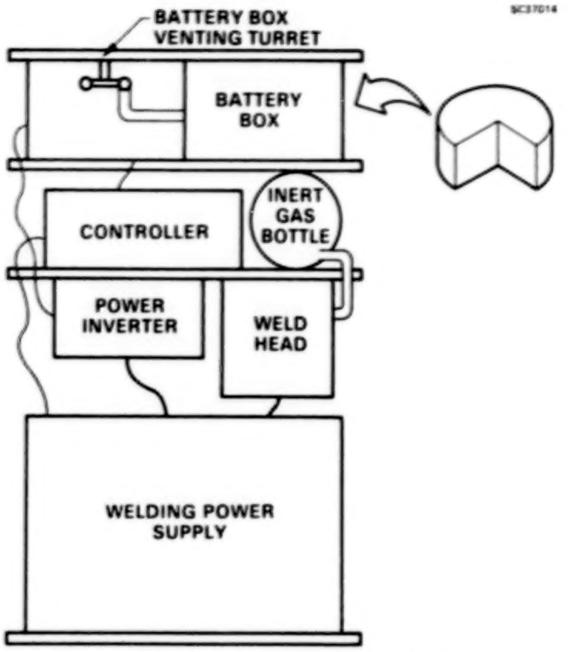

Fig. 1 Cross section of payload G-169.

GTAW POWER SUPPLY

The GTAW power supply is a modified System Technika International Nika Power 100. The Nika 100 is microprocessor based, allowing the storage and control of welding schedules. The power supply operates on 115 Vac @ 60 Hz. The power supply receives ac current and converts it to dc current for welding. The output characteristics of the power supply are dependent on the weld schedule to be used, that, in turn, being dependent on the material to be welded.

GTAW ORBITAL TUBE WELD HEAD

The orbital weld head is a modified System Technika International model 6003 Orbital Tube Weld Head. The model 6003 will accommodate up to a two in. outside diameter tube. The weld head includes a "U" style clamp, that prevents the tube from rotating. A tungsten electrode is mounted in a gear-driven track that rotates around the tube. The electrode consists of a rod of tungsten with 2% thorium, 0.0625 in. in diameter. A schematic diagram of the weld head is shown in Fig. 2. The weld head houses a chamber that is purged with an inert gas to prevent oxidation of the weld. A gas line inside the tube gives gas coverage to the underside of the weld, preventing oxidation of the specimen.

DC TO AC POWER INVERTER

The Nika 100 requires 115 Vac @ 60 Hz for operation. Since the power source for the payload is dc batteries, the production of ac current from the dc source is accomplished by means of a power inverter. The inverter chosen is the SPS 1607A Static Power Inverter manufactured by K.G.S. Electronics. The inverter receives 28 Vdc and inverts it to 115 Vac @ 60 Hz at a 1.2 to 1.6 KW output.

SEALED BATTERY BOX

The battery box is a 6061-T6 aluminum core internally coated with a nonconductive, electrolyte resistant material. The bottom plate is recessed out to

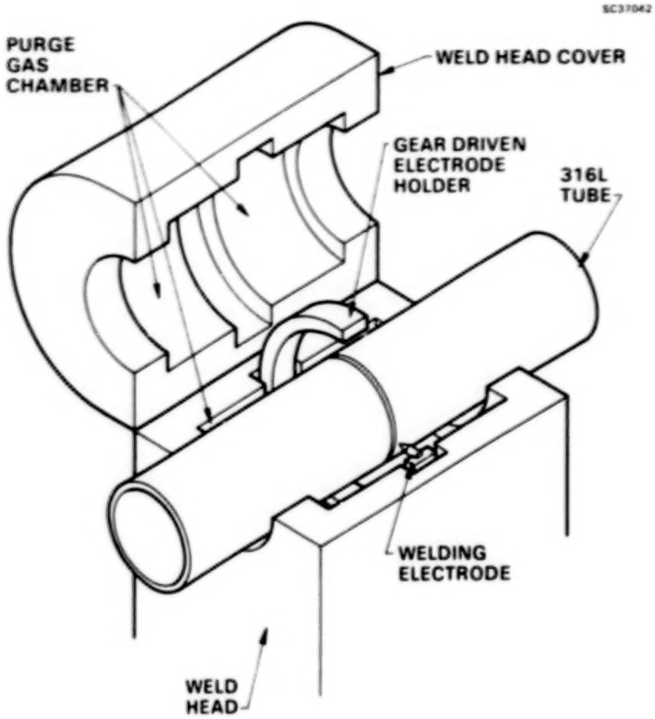

Fig. 2 Schematic diagram of in-place tube weld head.

secure the batteries. A mid-shelf made of plexiglass supports the top of the batteries. The top plate contains a vent that is plumbed up to the venting turret. Along the box sides are contact points for charging, power output, and thermistor leads. Before space flight the top and bottom plates will be sealed to the box via an "O" ring, compression fit to prevent gas leakage.

BATTERY PACK

The battery pack consists of 37 Gates Cyclon "J" cells. The "J" cell is a 2 V, 12.5 Ah battery. The battery pack consists of 3 separate subpacks of batteries all housed in the sealed box. The welding power supply requires 28 cells, the payload heaters need 6, and the controller needs 3 cells.

INERT GAS PRESSURE VESSEL

Argon is an inert gas commonly used to protect the weld pool from oxidization during solidification. In order to reduce the environmental parameters affecting the weld, an inert gas flow over the molten zone is used. During the welding process, an argon pressure bottle supplies a constant flow of gas purging the welding area of any other gases. The bottle is a spun aluminum core wrapped with fiberglass, manufactured by Structural Composite, Inc. A valve and regulator are used to reduce the bottle pressure to a safe line operating pressure.

PAYLOAD CONTROLLER

The payload controller consists of a Program Logic Sensor (PLS), a timer, and an analog to digital comparator (see Fig. 3). The PLS has two functions: one is to activate the welder upon indication of appropriate operating temperature, and

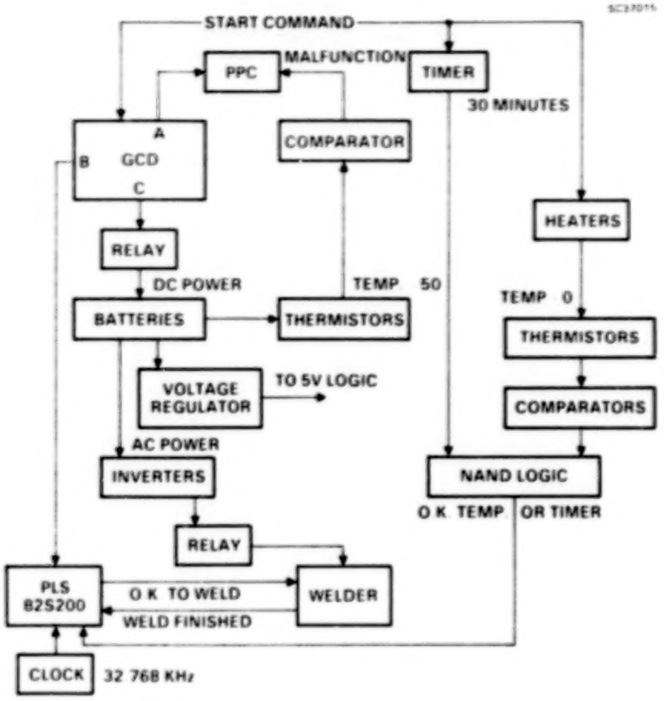

Fig. 3 Payload G-169 electronics block diagram.

the other is to send a signal to the GCD (gas control decoder) to interrupt power to the payload in the event of a thermal runaway (battery over-temperature). Upon payload activation the timer is started. The only function of the timer is to signal the PLS to attempt a weld start even if proper temperatures are not reached by a preset time, so at least some sort of data may be obtained. The analog to digital converter reads the analog signals coming in from the temperature thermistors and converts them to digital signals for use by the PLS.

PROBLEM ANALYSIS

During the development of G-169 the following problem areas were identified and addressed: (1) battery selection; (2) sealed battery box design and venting; (3) temperature control; and (4) electromagnetic interference (EMI) production.

BATTERY SELECTION

The Nika 100 requires 115 Vac at 60 Hz and converts it to dc power for welding. The initial battery pack configuration used dc battery power interfaced directly to the welder dc power input. Unfortunately, the dc to dc interface requires seven different voltages for welder operation, and thus seven different battery packs. If any one of the seven failed to produce its required power, the payload could be inoperative. Thus, an alternate power supply approach was required.

The second option, which was adopted in the final design, is to take the dc battery power and run it through an inverter to produce the ac current necessary to operate the standard Nika 100. The Nika 100, a very reliable power supply, is allowed to distribute the power as needed. This second method is obviously simpler and more reliable.

The testing of a battery to show that it is safe for space flight is an arduous task. Because of this a decision was made to use a battery that had already met the requirements for space flight. A logical battery choice is one of the Gates cells which have been used frequently in space payloads. Because of the payload's large power requirements, the first choice was the Gates Cyclon "BC" cell. After some research it was discovered that the "BC" cell had not yet met the requirements for space flight. The next choice was the Gates Cyclon "J" cell. The "J" cell is a 2 V, 12.5 Ah lead acid battery that has been proven safe for space flight.

SEALED BATTERY BOX DESIGN AND VENTING

The payload requires 37 Gates Cyclon "J" cells for operation. Because of the large number of cells, the potential exists for the production of explosive gases. Thus, as a part of a safety review NASA required that the battery package be vented out of the canister. A safe venting system requires a sealed metallic, nonconductive electrolyte resistant battery box, battery supports, and the necessary plumbing to the canister lid.

The battery box has an aluminum core with a nonconductive, electrolyte resistant internal coating. The batteries have top and bottom restraint plates to ensure stability against vibrational loading. A clearance of 0.50 in. exists between the top of the batteries and the battery box lid.

The plumbing from the battery box lid to the canister lid consists of VCR fittings manufactured by Kilsby Roberts Co. The VCR fittings are high pressure, close tolerance fittings used to connect tubing. All plumbing parts are stainless steel and are butt welded together.

TEMPERATURE CONTROL

Two temperature control problems have been identified. One problem is the effect of below 0°C temperatures on the microcircuitry. The majority of the electronic components used on G-169 meet military specification (subzero operation), but there are a few that do not. Operation of nonmil spec chips in subzero temperatures can cause failure. To prevent failure from occurring, heaters are located around the temperature critical circuitry. Upon activation of the payload the heaters are turned on if subzero temperatures are encountered. Once above zero temperatures are indicated by the thermistors, a signal will be sent from the PLS to the welder for activation.

The second problem is concerned with battery over-temperature. Because of the large amount of current required, excessive battery temperatures could occur. To prevent the batteries from overheating, temperature thermistors are used to sense temperature extremes. If a thermistor indicates excessive temperature a signal is sent to the GCD to shut down the system.

ELECTROMAGNETIC INTERFERENCE (EMI)

Electromagnetic Interference (EMI) is a high frequency electromagnetic wave. When an electrical current is passed through a wire a magnetic field is set up. The greater the current the greater the magnetic field. A high frequency alternating magnetic field produces an electromagnetic wave.

EMI can travel through air, up electrical cables, or along any other conductive path. Any type of device capable of receiving high frequency waves can receive EMI output. Upon receipt of EMI a current is produced. If the current produced is high enough, damage to the system can occur. EMI can activate or deactivate an idle or running system. EMI can seriously affect computers and radio communications. The Nika 100 utilizes a high frequency starter to initiate the arc. This starter is a major producer of EMI.

The standard GAS canister will attenuate up to 70 dB of EMI. It is strongly suspected that the combination of the power supply and the power inverter, both EMI producers, will exceed the 70 dB limit. EMI can be measured by the use of a spectrum analyzer with a calibrated antenna. EMI is effectively shielded by the use of copper screen, metal foils and metallized elastomer gaskets. It is desirable to entrap EMI as close to the source as possible.

EXPERIMENTAL HYPOTHESIS

To date no data exist on Gas Tungsten Arc Welding in space. The United States, the USSR and West Germany have done considerable research in other areas of microgravity welding.

The exact influence that gravity has on weld effectiveness is not known. A majority of space welding experiments show areas of commonality, but there are areas of discrepancy. The effects of gravity can be seen in buoyancy driven convection, surface tension, bead geometry, hydrostatic pressure, and removal of trapped gases. In a microgravity environment some of these conditions have negligible effects.

In welding, the effects of gravity are most important in determining the properties of the solidified material. Although gravity has no direct effect on grain structure or other microstructural properties (these are determined by crystallization kinetics, which in turn is controlled by short-range intermolecular forces), it can, however, indirectly affect solidification through its effects on fluid motion [1]. The motion of the liquid metal is a major factor in the stability of the pool and also, through convection, affects heat transfer within the pool thereby controlling the penetration and cross-sectional profile of the weld fusion zone [2]. The elimination of the buoyancy driven convection may have the effect of substantially reducing or eliminating macro- and micro-segregation from the solidified weld [3].

Previous experiments show a correlation between a microgravity environment and a more uniform grain size throughout the heat effected zone. This could possibly be accounted for by the lack of buoyancy driven convection, thus creating a slower solidification rate. The solidification rate is shown to also be a function of the thermal conductivity of the specimen.

The lack of buoyancy driven convection could prevent the removal of entrapped gas bubbles in the fluid metal. The entrapped gases could cause potential voids and an increase in the porosity in the space-welded specimen. The entrapped gases could chemically alter the corrosion-resistant properties of the stainless steel.

The shape of the fluid weld pool in a microgravity environment is a subject of controversy. One theory suggests that the absence of gravitational and hydrostatic forces will cause the liquid pool to take on a shape that minimizes surface energy. A minimum surface energy configuration would be spherical in shape. This analysis suggests that the bead shape will be determined solely by surface tension.

An alternate theory suggests that in a microgravity environment a liquid medium has a greater affinity for its parent material then it would in a one "g" environment. This affinity could cause the fluid metal pool to be drawn back to the parent material, and thus result in a thinning of the weld pool. A horizontal cross-sectional view of the weld pool would show an hourglass shape. This theory states that surface tension is the driving force in weld pool shape but that the bead geometry is affected by the affinity for the parent material.

The specimen to be welded is stainless steel 316 L, a material with low thermal conductivity. From the data analyzed and the fact that the specimen has a low thermal conductivity, one is lead to believe that the space-welded specimen will exhibit a heat-effected zone almost entirely comprised of small grains. At the interface of the heat-affected zone with the parent material, macro- and microsegregation should exist producing a grain size gradient.

This analysis suggests that the bead geometry of the space-welded specimen should be about the same as its earth-based counterpart, a shape somewhere between what the two above stated theories suggest. G-169 utilizes an argon purge to protect the weld from oxidation. This purge, being a gas flow, could possibly create convective cooling, thus allowing convective heat transfer. The temperature gradient produced by the convective cooling could cause a migration of any entrapped gases to the weld surface. Overall, the weld produced on G-169 should be a better weld in terms of strength and penetration. The physical appearance should show a bead that is similar to its earth-based counterpart but with a smaller, more uniform granular structure.

ACKNOWLEDGMENT

Without the significant support of the Rockwell International Science Center, through its Independent Research and Development Program, this work would not have been possible. Additional assistance from Rockwell's Rocketdyne and Space Stations Systems Divisions as well as from ST International is also gratefully acknowledged.

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Use of Lightweight Composites for GAS Payload Structures

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Abstract

A key element in the design of a small self-contained payload is the supporting structure. This structure must support the experiments and other components while using as little space and weight as possible. Hence, the structure material must have characteristics of being both strong and light. Aluminum was used for the structure on the first Purdue University payload, but consumed a relatively large percentage of the total payload weight. The current payload has a larger power supply requirement than did the previous payload. To allow additional weight for the batteries, a composite material has been chosen for the structure which has the required strength while being considerably lighter than aluminum.

A radial fin design has been chosen for ease of composite material lay-up and its overall strength of design. A composite plate will connect the free ends of the fins to add strength and reduce vibration.

In this presentation I will describe the physical characteristics of the composite material and the method of open lay-up construction. I will also discuss the testing, modifications, and problems encountered during assembly of the experiments to the structure.

INTRODUCTION

The use of composite materials in the aerospace industry is rapidly becoming a standard practice. For some time, control surfaces, access panels, engine nacelles and radomes of most modern commerical aircraft have been made of such materials. The vertical take offs and landings of the Harrier fighter plane are made possible through the use of lightweight composites. In the business aircraft world, the new, soon-to-be certified turbo-prop Starship is built mostly of composite materials. There are already many private aircraft in the air today which are made exclusively from composites. The Space Shuttle is no exception, with its huge cargo bay doors and many other components being made with these strong lightweight materials.

A key element in a Small Self-Contained Payload (SSCP) is the supporting structure. This structure must support the experiments and other components while using as little space and weight as possible. The design constraints imposed by the SSCP canister require that the structure be rigidly

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affixed only to the NASA-furnished experiment mounting plate; only stabilizing rubber "snubbers" or lateral mounts can be used to brace against lateral motions.

COMPOSITES VS. ALUMINUM

The aluminum structure used on the first Purdue University Small Self-Contained Payload proved to be more than adequately strong to support the experiments and control units (see Snow et al., 1985 for a description of this structure). However, there is planned for the second Purdue SSCP an experiment which will use a large amount of electrical current, and thus requires an extensive (and heavy) set of batteries. Another set of heavy items scheduled to be flown are the cans of thermal salt which will be used to control the temperature in the canister throughout the flight (Stark, 1985).

The last heavy item in the original design for this second payload was the structure itself. Originally projected to be made from aluminum, it was found to consume an unacceptably large percentage of total allowable payload weight. A material that was strong, easily manufactured, relatively inexpensive and most importantly light weight was needed for a replacement. Composite materials met all of these requirements.

It was decided to use a "sandwich" type construction wherein a foam core is covered (laminated) with several layers of glass cloth and resin. In our case, "DERAKANE" vinyl ester resin laminated with C-glass forms the outer portion of the sandwich. As different parts of the structure had different strength requirements, 4.5 and 20 lbs/cu. ft. polyurethane foam was used to form the core. The material chosen was readily available from an aircraft company which produces all-composite aircraft kits, one of which is being constructed at Purdue.

FABRICATION

The techniques used to fabricate structures from composite materials range from direct forming in large (and expensive) autoclaves to a simple open lay-up. The open lay-up procedure was chosen for present purposes because its low cost and practicality. It requires only easily found hand tools and common shop machinery. It is particularly attractive for an educational SSCP as the student-workers can quickly learn the techniques of making and combining simple shapes.

THE STRUCTURE

The three radial fin design shown in Fig. 1 has been chosen for ease of composite material lay-up and its overall strength. This structure is made up of 3 basic parts: a circular base (which is to be bolted to the NASA-furnished experiment mounting plate), 3 rectangular fins on which the experimental hardware is mounted, and a top plate.

The base and fins are made of a 1/2", thick 20 lb/cu. ft. foam core laminated with 4 layers of glass cloth on each side. These four pieces were layed-up oversized then cut to the indicated dimensions with a band saw. The fins were then attached to the base using resin and a thixotropic agent. This held the fins in place while glass cloth reinforcing strips were laminated along the edges in the shape of L-brackets. Holes were then drilled in the base to accommodate the mounting bolts.

The top plate serves to reduce the amplitude of vibrations of the free ends of the fins and provides a strong supporting surface for the required lateral mounts or "snubbers". This plate was constructed from 1/3", 4.5 lb/cu. ft. foam with 3 layers of glass laminated on each side. To reduce weight and allow for easier accessi-

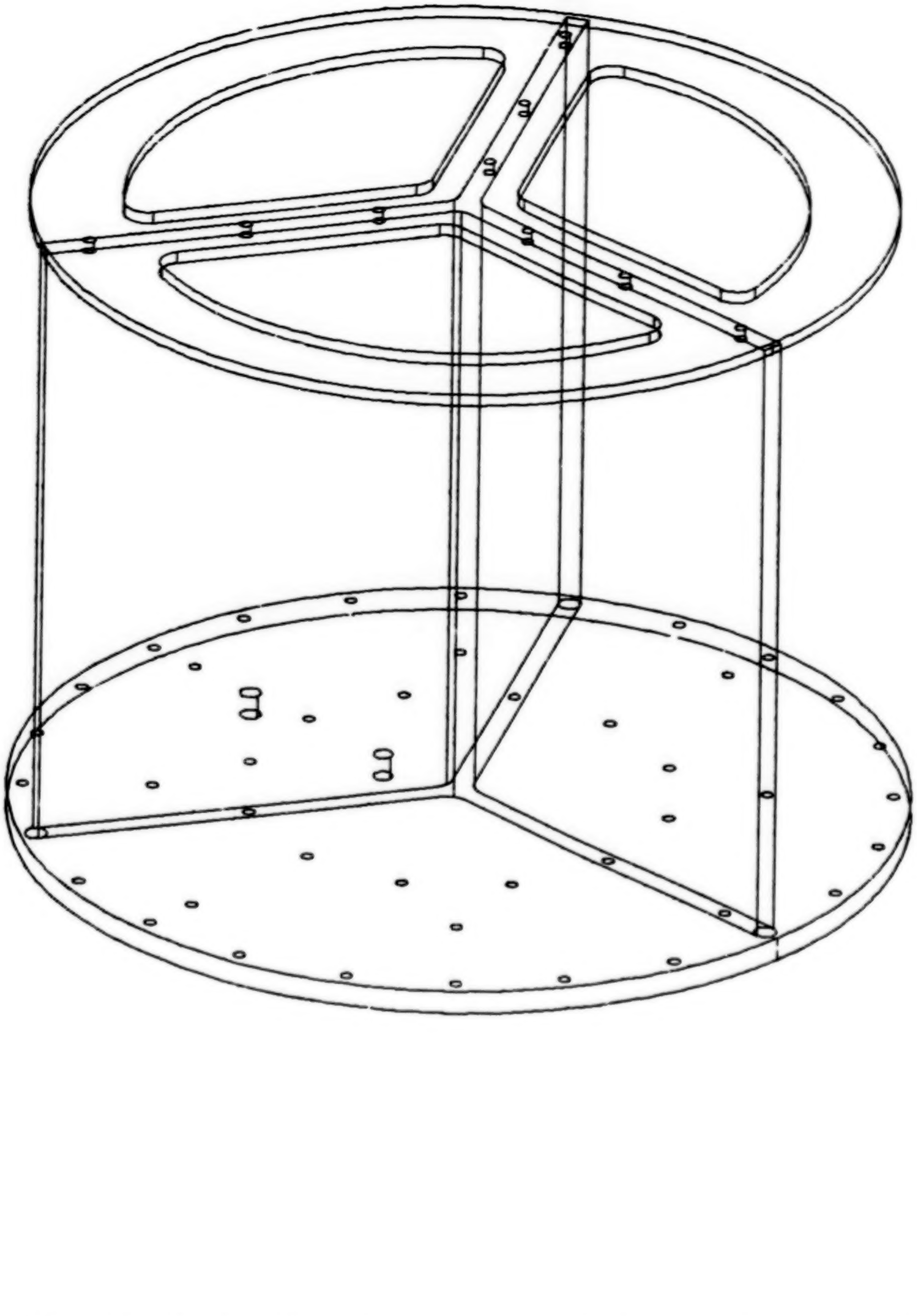

Fig. 1. Schematic showing the major components of the prototype supporting structure for PUGAS II.

bility, the top plate was trimmed down with 3 lightning holes. Holes were then drilled to allow for the Sur-Lock fasteners to pass through and attach to the ends of the fins. This top plate will be held in place with standard aircraft hardware; it can be quickly removed and set aside for improved accessibility. The lateral mounts will be attached to the top plate spaced equi-distantly around the outer circumference.

THE ENVIRONMENT

The vibration the payload will encounter during launch will be simulated on the structure both prior to and after the attachment of the components. Adjustments to the structure (i.e., reinforcements) will be added as needed.

Using thermal salt as a passive control system, the temperature within the canister should remain near room temperature. However, the structure material would retain its strength through a temperature range of -200°F to 300°F. Thermal expansion of the material is negligible through a 300° temperature change. The aluminum mounting plate will expand and contract more than the composite structure and this will be taken into consideration.

Another environmental concern is the waste heat the materials processing experiment will give off. Upon testing, insulation and closeness of this experiment to the thermal salts will be adjusted.

SUMMARY

The role of composites in the aerospace industry will continue to grow because of its proven performance and desired characteristics. The information we receive from this payload will help us and others in determining the best designs and materials to use on future payloads. Perhaps in a few years, the use of composite structures in GAS payloads will be the rule instead of the exception.

ACKNOWLEDGEMENTS

The project team members would like to thank Dr. Harold Ritchey for donating the canister reservation to Purdue and Dr. John Snow, our faculty advisor, for his help and guidance. Ms. Helen Henry assisted by typing this manuscript.

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PHYCOMYCES IN SPACE:
A Problem in Bioengineering

by

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Get Away Special Project G-285
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ABSTRACT

Sustaining life with total automation is a difficult problem for GAS canisters. The length of time between setting the experiment and flight, the conditions of a completely sealed container, no guarantee on launch delay, orientation and the possibility of contamination all tend to exclude experiments with living matter. This experiment examines the growth of a nontoxic, everyday fungus, Phycomyces, in a microgravity environment. Data from this experiment will help define the mechanism by which plants determine the direction of gravity.

The bioengineering problems were solved only after numerous tests and design changes. Phycomyces normally have a shelf life of approximately one week. Storing the fungus for two months, activating the fungus for growth and precise timing were the major obstacles. Solutions were found for storage by drying the fungus spores onto pieces of filter paper. Activation occurs when this filter paper is dropped onto the growth medium, via a solenoid system. The problem of timing is partially solved by growing more than one chamber of the fungus at different time intervals. This experiment proves that the simpler a design is, the better it works.

INTRODUCTION

When placing living matter into a microgravity environment many problems concerning the living requirements of the organism must be solved. In GAS experiments the problems are even greater due to the unmanned conditions of the GAS canisters. Everything must be automated. The G-285 experiment with the fungus Phycomyces encountered many bioengineering problems due mainly to time factors. The short life span of the fungus, one week, and the delay between setting the experiment and flight was the greatest complication. This experiment is also unique since it runs through launch. NASA has strict requirements for this time period. The possibility of a launch delay required extra attention. The *Phycomyces* experiment is in a GAS canister with two other experiments and allotted space and weight are little.

PROBLEMS AND SOLUTIONS

The first step in this experiment, as in any experiment, was to determine exactly what needed to be accomplished. The fungus is to grow to the desired stage of life, by launch, in the upright position. At launch the *Phycomyces* will be placed in a horizontal position and stressed by the force of launch. Once in the microgravity atmosphere pictures will be taken to determine the new direction of growth. Normally when *Phycomyces* are placed in a horizontal position they bend to grow against the force of gravity (See Figure 1). The outcome of this experiment may help determine the gravireceptor (gravity determining) mechanism of the fungus.

The conditions required by the fungus for growth are not complex. They need the growth medium containing its basic nutrients and air. The only obstacle here is keeping the growth medium moist for the approximate time of two months. To solve this growth chambers will be built completely sealed with added moisture inside. The growth medium will be placed in the bottom of the chamber. This sealed growth

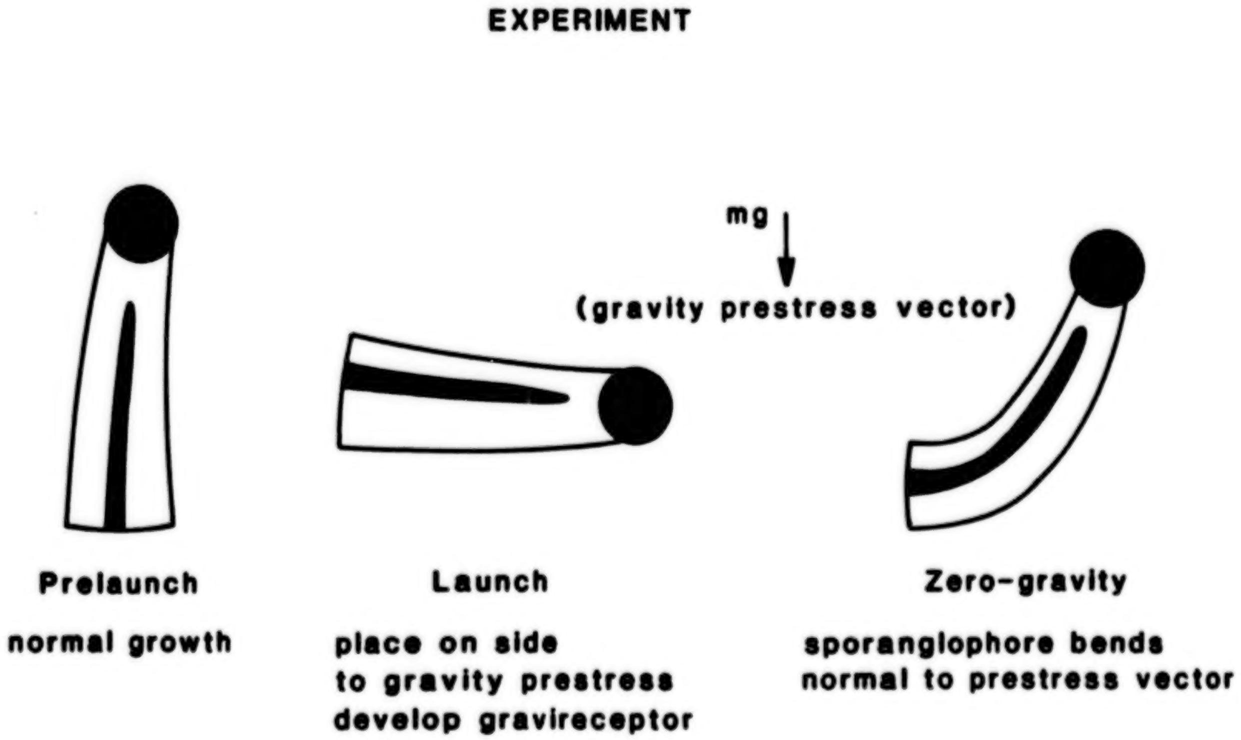

Figure 1.

chamber also solves the problem of possible contamination of this or the other experiments. The growth chamber is approximately one inch by three and one-half inches and will be made out of polycarbonate plastic.

To get the fungus to grow after two months dormancy posed the biggest bioengineering problem. The growth initiation system also underwent the most changes in design. The fungus grows from spores. The first idea was to freeze dry the spores to keep them dormant and heat shock them to restart growth. This design required too much energy. Another idea was using the spore stock solution but this was too hard to keep for two months. Many other ideas were proposed that that required refrigeration. This simply took too much energy. The final idea is much easier. The spores will be dried onto small pieces of filter paper and the pieces of paper will drop onto the growth medium. This system is simpler than anyone imagined it could be.

The next problem encountered was how to drop the pieces of filter paper holding the dried spores onto the growth medium. The spores begin growth when they recieve the needed nutrients from the growth medium. To be in the proper stage of life at launch they must begin growing three days before launch. Therefore they must drop onto the growth medium three days prior to launch. It was suggested to use solenoids to push the filter paper onto the growth medium. Various methods were proposed to do this. One version was to push the filter paper in from the side. The hole through which the paper would fall would be covered with wax paper or similar material to keep the growth chambers environment intact. The solenoid would break the wax paper when pushing the filter paper out. The problem with this method was space. There was not enough room for the solenoids on the sides of the growth chamber. Another idea was to use a solenoid to push on an eye dropper bulb causing a blast of air to push out the filter paper. This method did not produce enough pressure to accomplish the job. The idea of using solenoids was dropped for a while and other methods were considered. One proposed was to have the filter paper resting on a strip of aluminum above the growth medium. A motor would pull out the aluminum strip. The filter paper would fall when the aluminum strip was pulled out of the growth chamber. The motor, though, took too much energy and space.

The answer to the growth initiation problem was in solenoids after all. Solenoids were found that were small enough to fit on the bottom of the growth chamber. A tube will come through the growth medium covered on the top with wax paper. The solenoid pin will be tapered and fit inside the tube with the filter paper on top. The solenoid pushes through the wax paper, pushing out the filter paper letting it fall around the outside of the tube.

Orientation of the Phycomyces is another bioengineering problem. The design for putting the Phycomyces into their proper orientation is also simple. Ideas for motors to turn the growth chamber weren't reasonable because of the energy restrictions. A gimbal system was designed that runs only by the forces of gravity and launch and by springs. The growth chamber will be attached to the front of the gimbal system. The gimbal allows the growth chamber to turn freely until launch keeping the fungus verticle to the force of gravity. At launch the force turns the gimbal 90 degrees to put the growth chamber in a horizontal position. The gimbal locks into place at this time with a spring mechanism. The gimbal system will be built out of aluminum.

The possibility of a launch delay is a large problem that cannot be fully corrected. The short lifetime of the fungus requires delicate timing. A timer will be set when the GAS canister is closed for the proposed launch date. The timer will pulse the solenoids to begin the growth of the fungus. As a precaution there will be four separate growth chambers attached to the gimbal system front. Each chamber will have its' own solenoid below it and these solenoids will be pulsed about one day apart. This separation will account for up to a one week launch delay. After one week there will most likely be no valuable data.

The camera to be used is a Nikon F-3 model. A timer will be set off by a gravity switch at launch and run for fifteen minutes. This timer will start the camera, autowinder and intervalometer after the vibrations of launch have passed. Thirty-six pictures will be taken two or three minutes apart. When the pictures are done so is the experiment.

A micro-micro lens is to be used. The fungus is less than one millimeter in diameter. The distance between the fungus and the lens will be less than ten inches (See Figure 2). The equipment was found by experimenting with various lenses to get clear pictures. The pictures must allow determination of the direction of growth.

Where the Phyco Roam

The Phycomyces Experiment Space-Pak

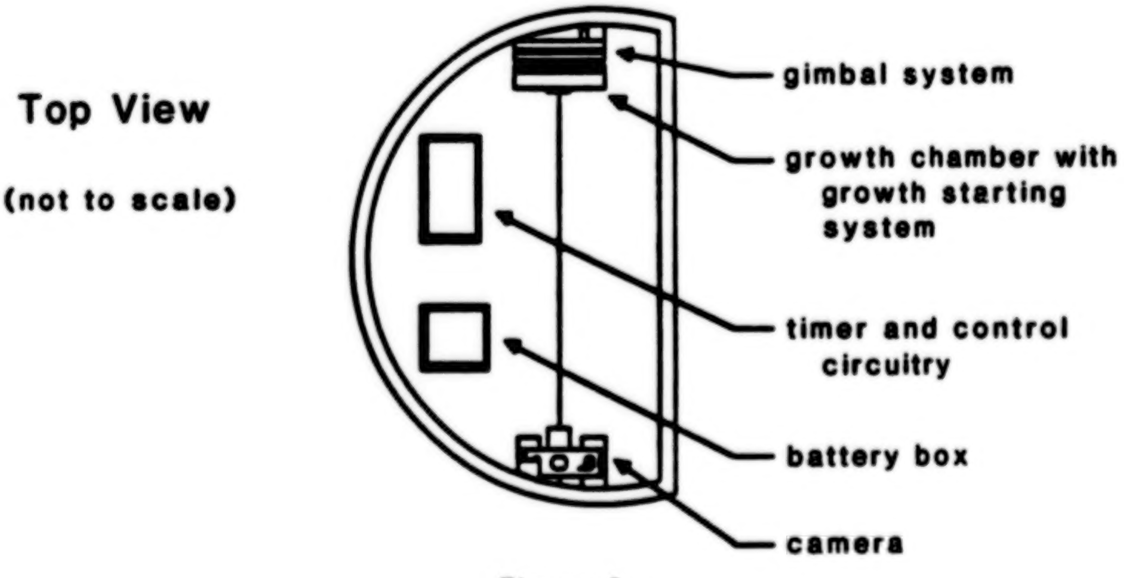
Top View
(not to scale)
gimbal system
growth chamber with growth starting system
timer and control circuitry
battery box
camera

Figure 2.

The lighting creates a bioengineering problem. Light must be used to get the photographs but the reaction of the fungus to the light must be considered. The experiment will be run in complete dark except for when the pictures are being taken. There are no light requirements for the growth of Phycomyces. In fact there can be no light during this particular experiment for accurate data. The fungus will grow towards a light source if one is available. The exception to this rule is red light. Phycomyces is blind to red light. When the pictures are being taken, the intervalometer will also pulse small halogen light bulbs covered with a layer of red and placed on the growth chamber. These light bulbs were chosen for their brightness and for their low energy consumption. Originally a regular camera flash, covered with red, was to be used. This was not used because of NASA requirements. LED lights were considered but did not give off enough light.

CONCLUSION

The requirements or reaction of the fungus had to be considered with all processes and systems proposed. This turned all problems into bioengineering problems. Most of the solutions were simpler than originally thought. The design of all experiments should be kept as simple as possible. As few requirements for growth as Phycomyces has problems with the reaction of the fungus constantly arose. Sustaining life in a completely automated environment is difficult enough and further complications in the design only danger the success of the experiment.

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NORSTAR Project

Norfolk Public Schools Student Team for Acoustical Research

by

Ronald C. Fortunato

Topic

The NORSTAR Project (GAS-325): The First High School Student-Run Space Flight Project

Abstract

Development of the NORSTAR (Norfolk Public Schools Student Team for Acoustical Research) Project includes the definition, design, fabrication, testing, analysis, and publishing the results of an acoustical experment. The student-run program is based on a space flight organization similar to the Viking Project. The experiment will measure the scattering transfer of momentum from a sound field to spheres in a liquid medium. It is hoped that the experimental results will shed light on a difficult physics problem - the difference in scattering cross section (the overall effect of the sound wave scattering) for solid spheres and hollow spheres of differing wall thicknesses.

The NORSTAR Project represents the first high school student-run space flight project ever attempted. The project includes the definition, design, fabrication, testing, analysis, and publishing the results of an acoustical experiment which will fly on the space shuttle in 1987. The project also represents the first time that an entire team of NASA scientists, engineers, and managers have volunteered to support a high school project.

The NORSTAR Project is a flagship example of a partnership in education between a public school system and private and public agencies from the community. The Norfolk Public Schools and the NASA Langley Research Center have embarked upon perhaps one of the most unique and fruitful community involvement programs to date, and one which has already received international attention as a prototype for other school systems to duplicate. In the first year, the project has generated equipment and consultant support from the educational community including Old Dominion University, the College of William and Mary, and Norfolk State University; and from the industrial sector including Nikon Corporation, Tandy/Radio Shack, Tektronix Incorporated, Valpey-Fisher Corporation, Town Point Center, and the list goes on. The project curriculum has been developed to incorporate an interdisciplinary, integrated approach in order to facilitate the most effective learning processes for areas of study including physics, mathematics, computer programming and applications, chemistry, communication and speech making skills, and utilizing a team approach to solve problems.

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EVOLUTION OF THE *NORSTAR* PROJECT

In the fall of 1983, the NASA Langley Research Center initiated a request for experimental proposals from some 25 school systems in Virginia. The winning school system would be sponsored by NASA and given a "ticket" to develop a small self-contained payload operated under the Get Away Special program of the NASA Goddard Space Flight Center in Greenbelt, Maryland. This "ticket" is a container which houses the experiment at a cost of $10,000 and is placed in the cargo bay of the space shuttle.

At that time, a science extended day class of the Gifted and Talented program under the direction of teacher Ronald C. Fortunato was converted into a research proposal team. The team researched and developed three proposals, which were submitted to the Director of the Langley Research Center, Dr. Donald Hearth. All proposals were reviewed, and by the spring of 1984, the proposed experiments by the Norfolk students were judged to be the most significant and promising by NASA officials, and the Norfolk project was chosen for inclusion aboard a 1987 flight of the space shuttle.

At this point, Dr. Joseph Heyman, a world renowned researcher in the field of ultrasonics from the NASA Langley Research Center became extremely interested in the Norfolk Public Schools' experiment proposal. The students had developed an experiment which was closely related to some of his own research, and as it has turned out, if the experiment runs successfully in space, a problem plaguing researchers for many years may be resolved by the student's space experiment. Dr. Heyman volunteered to be the NASA scientific consultant to the Norfolk students for this remarkable project and significant undertaking. At this time, the students developed an acronym for their project: NORSTAR - Norfolk Public Schools Student Team for Acoustical Research. The NORSTAR team consisted of students from each of the five high schools in the city.

Word spread around the Langley Center about this fascinating student experiment, and an entirely unexpected event occurred: an entire team of NASA scientists, engineers, and managers volunteered to serve as mentors for the Norfolk experiment. The significance of this event cannot be appreciated enough, for it enabled the NORSTAR Project to develop an organization which was similar to a genuine NASA space flight project. This offer by the NASA personnel demonstrated in profound terms their commitment and dedication to the education of young students. It is also astounding to note that several of the mentors were on the Viking Project which sent the Viking spacecraft to Mars. The students (and teacher) had no idea what amazing experiences and hard work they were about to get physically and emotionally involved with in the near future.

DEVELOPMENT OF THE *NORSTAR* PROJECT ORGANIZATION

It is the project organization that duplicates a NASA space flight project which makes NORSTAR a space flight project, and not just an experiment (please refer to Figure 1). The organization places a student responsible for managing a system related to a particular experimental function. A NASA mentor "shadows" each student at each position. The NASA mentors are often affectionately referred to as the Shadow Team. The student project scientist has a NASA scientist as his mentor (Dr. Heyman); the chief engineer has a NASA engineer as his mentor; the student electrical systems manager has a NASA electrical engineer as his mentor, etc. It is only because of this tremendous support at each key position of the organization, that we were able to make one more historical change in the program goals. The project could be designed to be student-run. Only because there was such a high level of expertise available for the students to rely on for resource support, the students could be allowed to determine the fate of their own experiment. All

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NORSTAR

NORFOLK PUBLIC SCHOOLS STUDENT TEAM FOR ACOUSTICAL RESEARCH

GETAWAY SPECIAL PROJECT ORGANIZATION 1985 - 1986

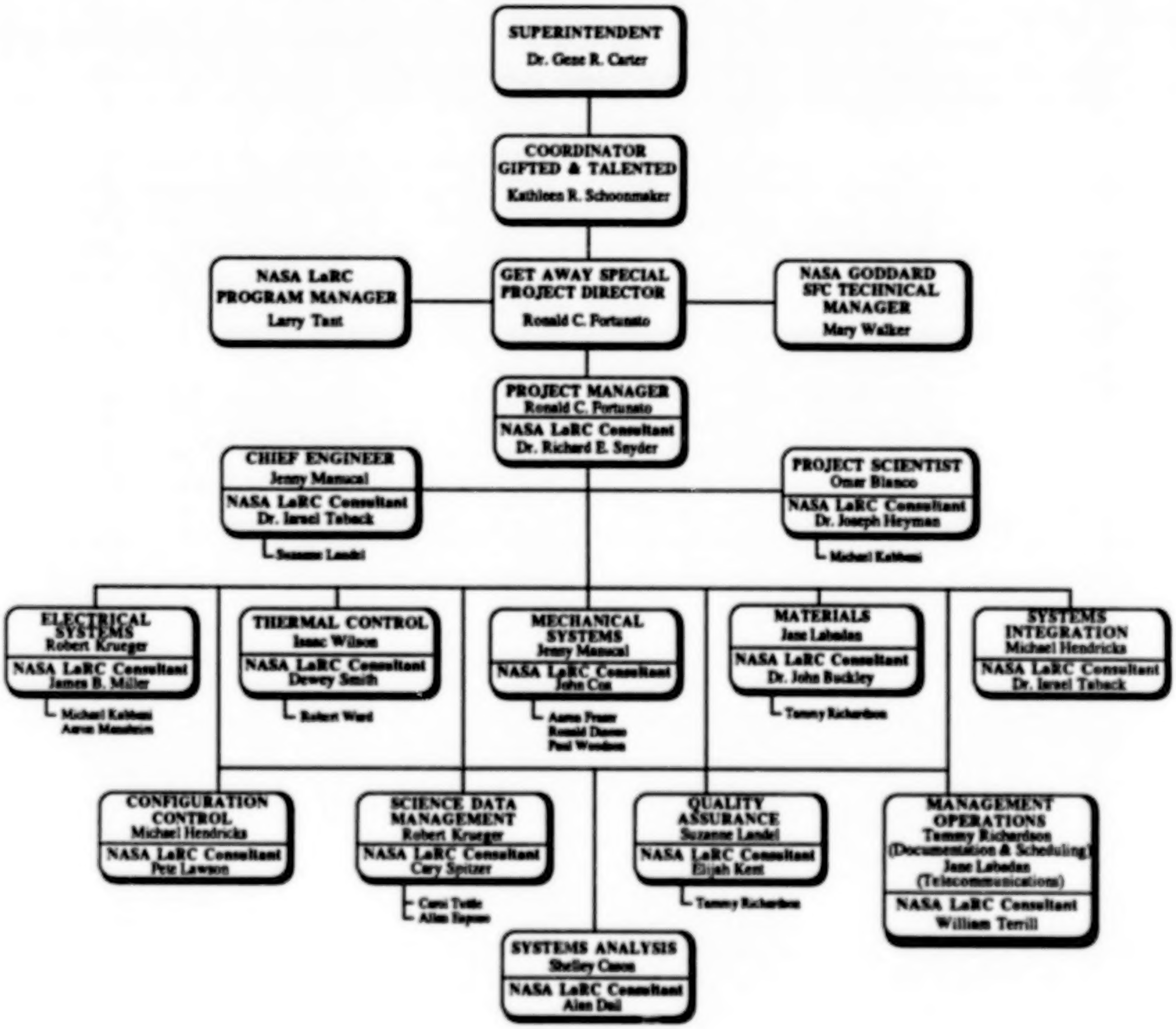

Figure 1.

mentors and teachers involved with the NORSTAR Project do not tell the students what to do. They develop all necessary and requested information required by the students to complete their tasks and to solve their problems, but the guidance is subtle. The students make their own decisions, and are allowed to make mistakes and to learn from them. The teachers and mentors make sure that the students do not head down dead ends, but allow them the freedom of following their own thoughts and ideas to fruition, and to express and develop their wonderful creativity in solving the multitude of problems which present themselves in a project of this nature. The students feel complete ownership of the experiment, yet know, respect, and appreciate the level of guidance they are receiving.

The Norfolk Public Schools demonstrated complete commitment to the project by generating several items of support. A clean room (relatively dust-free laboratory) was established at the Norfolk Technical Vocational Center with phone installations and computer networks set up so that the students could work on and communicate with NASA computers and mentors. The teacher (Mr. Ronald Fortunato) was assigned to the project on a full-time basis, and the students receive double weighted science elective credit. Each student is transported from his home school to the NORSTAR lab for a minimum of two periods per day to work on the project, and all students meet from 2:30 to 5:00 pm in the lab on Tuesdays and Thursdays. The afternoon sessions are used for group meetings which include a weekly status review delivered by each student manager to the rest of the team; for group communication integration sessions; and for running lengthy experiments. The students communicate with their mentors by phone whenever necessary, and meet personally with their NASA counterparts approximately every other week.

There is a very special reason for the NORSTAR laboratory being located at the Norfolk Technical Vocational Center (NTVC). The project draws on the support of several of the programs currently run by the center (see Figure 2). Students and teachers from these programs are directly involved with the development and fabrication of experimental components. Although not enrolled in the NORSTAR class, between thirty to fifty NTVC students are currently supporting the project, and feel ownership in the space flight experiment. The electronics program at NTVC supports the development of the experimental design and circuit board fabrication; the drafting program students draw the high quality mechanical designs required by the NASA personnel. The machine shop fabricates components to the specifications of the NORSTAR students. The word processing and reprographics program types all project documentation ranging from weekly status reviews and correspondence to research reports for publication. The welding program assists in fabrication of certain components in conjunction with the machine shop. The graphic arts students take the NORSTAR student designs and convert them into high quality posters, logos, and presentation material. The printing shop takes printed documents and develops publication quality materials. The data processing program works with the NORSTAR students in writing computer programs for data analysis of the ground based experiments.

The mechanism of the NORSTAR Project is far reaching and presently involves teachers from all five high schools. When the program director determines that one of the students is having difficulty understanding a particular concept, he differentiates the curriculum of that student. The problem area is identified, and the director writes a set of objectives, content area, and suggested activities which directly addresses the concept which the student is having difficulty with. The director then consults with the student and a teacher of that particular subject area at the student's home school. The curriculum packet is sent to the home school teacher, and the student makes contact with the teacher and sets up a one-on-one tutoring help session. The help session(s) are conducted, and the home teacher sends the results, progress, and recommendations to the director.

There is a transition which occurs when students graduate. All students in charge of subsystems are responsible for teaching younger students their jobs and responsibilities. This way, a new student may take over a subsystem upon the manager's graduation. Students are selected and brought into the program as sophomores. This allows a smooth transition and minimizes loss of time and information. The NORSTAR graduates are not lost to the program either. They are kept in contact with the project through communications and status updates which

***NORSTAR* Project Support from Programs at the Norfolk Technical Vocational Center**

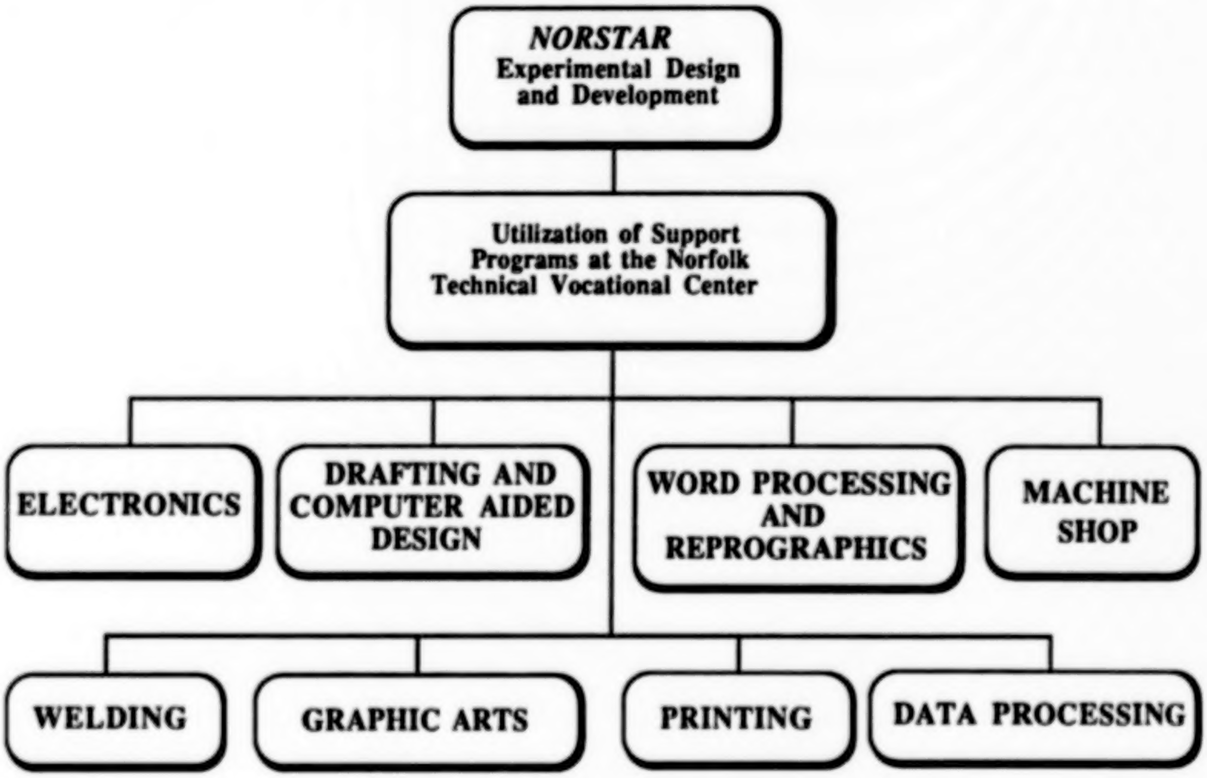
NORSTAR
Experimental Design and Development
Utilization of Support Programs at the Norfolk Technical Vocational Center
ELECTRONICS
DRAFTING AND COMPUTER AIDED DESIGN
WORD PROCESSING AND REPROGRAPHICS
MACHINE SHOP
WELDING
GRAPHIC ARTS
PRINTING
DATA PROCESSING

Figure 2

are sent to them by the regular students and the director. The graduates continue to have as much input into the project as their time allows.

THE *NORSTAR* EXPERIMENT

The title of the experiment is "Acoustic Radiation Momentum Transfer Measurement Utilizing Acoustic Phase System Techniques in a Microgravity Environment".

Acoustic scattering is a very important phenomena and has received attention recently in the field of Non-Destructive Evaluation. This is a process in which ultrasonic sound waves are used to detect flaws or weaknesses in solid structures such as the wing of a jet aircraft. Many scientists are trying to solve the inverse problem - to measure the scattering field and infer the scattering source - such as a crack in a pressure vessel. With that knowledge, we can insure the safety and reliability of critical structures.

The NORSTAR experiment will measure the acoustic radiation transfer of momentum from a propagating sound field to spheres in a liquid medium. Research in acoustic radiation force has been hampered by errors due to a suspension system which differs from an ideal system. Possible sources of error include surface tension of the suspension wire passing from air to the liquid medium; and attachment of the suspension to the sphere. The NORSTAR experiment will eliminate these errors by performing this experiment in a microgravity environment provided by a Get Away Special cannister mounted in the cargo bay of a space shuttle. Once in orbit, the microgravity environment eliminates the need for a suspension system and the errors associated with it. Flight data will be compared with ground-based control data. It is hoped that the experimental results will allow researchers to examine current and past data.

The NORSTAR experiment will utilize an acoustic phase system to measure sphere movement in addition to a photographic analysis technique. The system consists of a receiving transducer that will measure backscattering from a sphere driven by a driving transducer. Sphere velocity will be calculated by recording the phase-shifted wave reflected by the moving sphere. The momentum transfer can then be inferred through the use of the recorded data. Electronic circuits (mixers, filters, etc.) will detect and amplify the signal from the transducer before electronically storing this information. The NORSTAR project goals are therefore twofold: to determine the error present in a suspension system; and to determine the feasibility of the measurement system to determine sphere velocity.

This experiment can be performed only in the absence of gravity, and will provide important information concerning Non-Destructive Materials Evaluation, tissue characterization (determination of the depth of cell damage in burned skin), and the interaction between sound energy and solid materials in the absence of gravity (see Figures 3 and 4).

This high school project sponsored by the Norfolk Public Schools Gifted & Talented Program seeks comments from those in the acoustics community who would be interested in this experiment and wish to collaborate.

Any correspondence with the NORSTAR Project is welcomed, and may be addressed to:

NORSTAR
Norfolk Technical Vocational Center
1330 North Military Highway
Norfolk, Va. 23502
Lab phone: (804) 466-0701

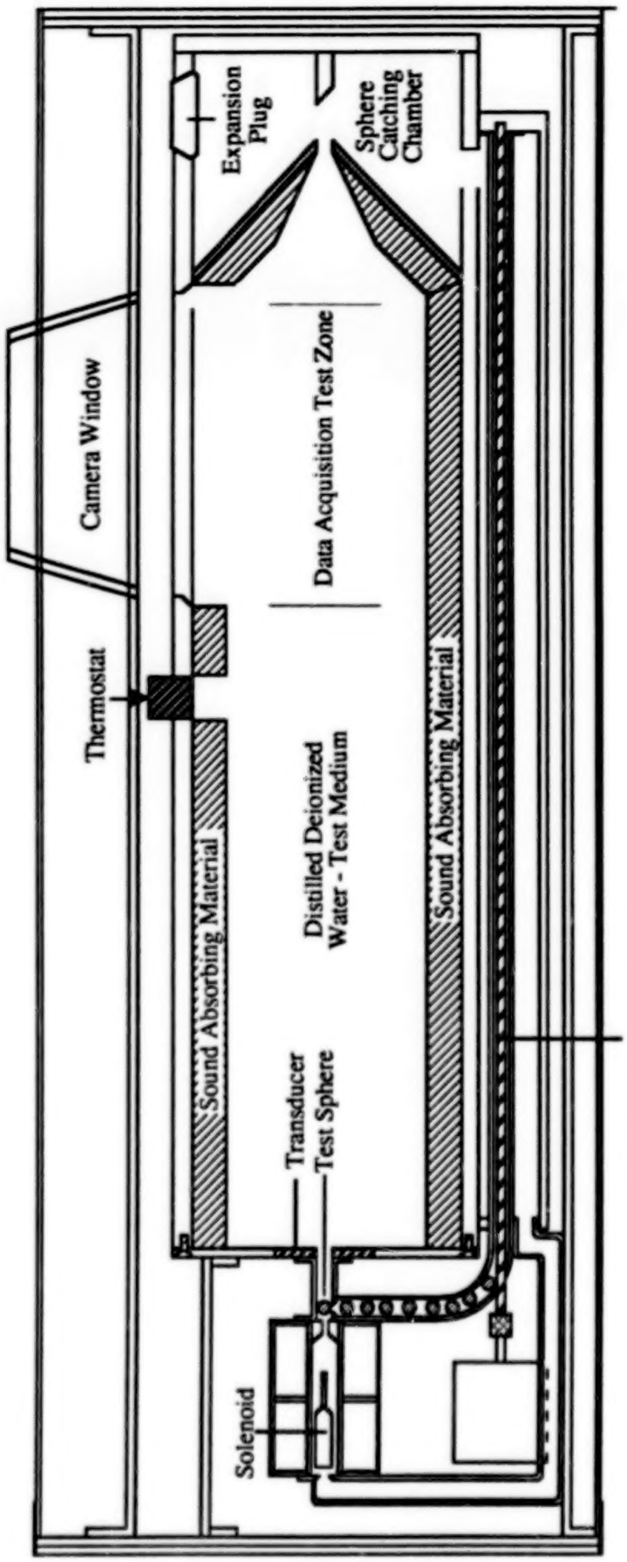

Figure 3

EXPERIMENTAL SETUP

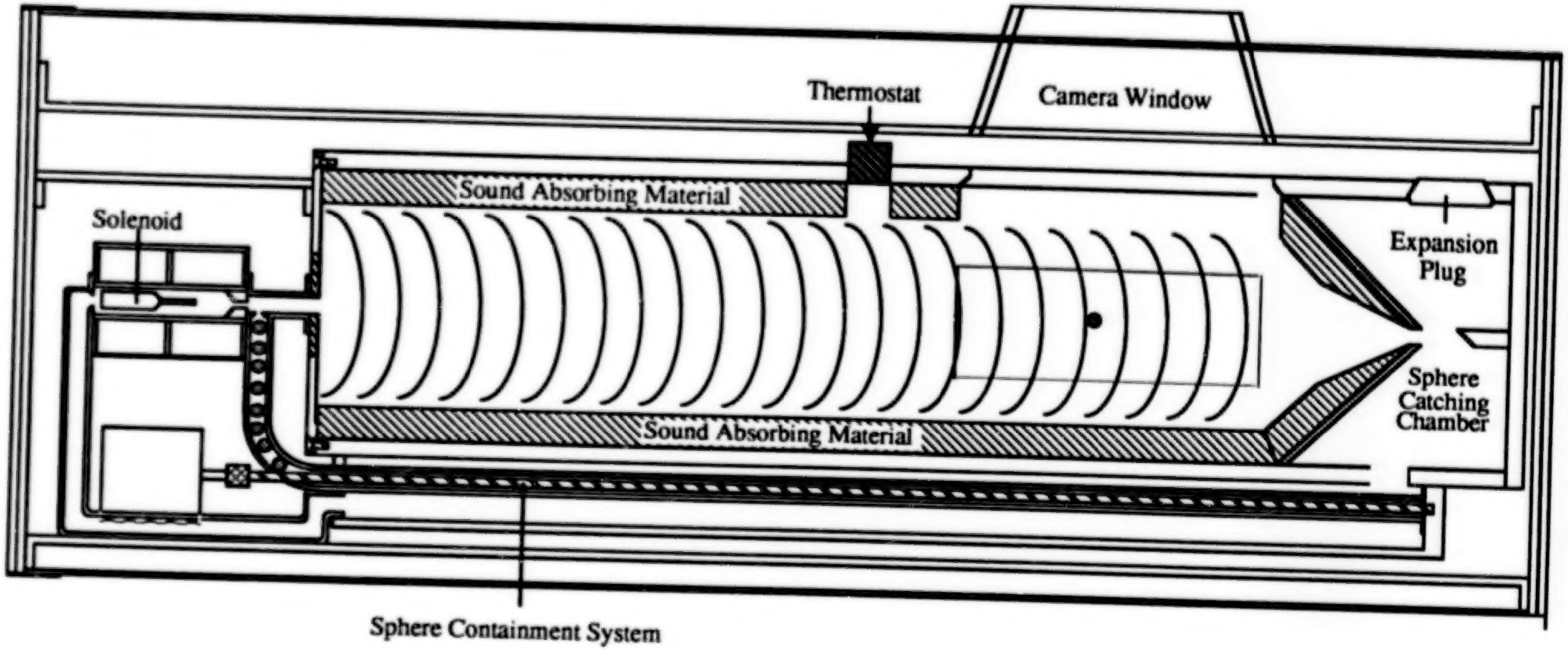

Figure 4

EXPERIMENT IN PROGRESS

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TOWARDS A BETTER MIRROR

by: David Hoffer
Telesat Canada
Ottawa, Canada

ABSTRACT

Telesat's Getaway Special competition was designed to promote interest in space among high school students in Canada. The winning entry proposed the manufacture of mirrors in microgravity and to compare the optical properties of these mirrors with similar ones made on earth. Telesat engineers designed and built the experiment which flew on the Atlantis shuttle on November 27,1985. This paper outlines the design evolution, its implementation, the manufacture and test of the GAS and the results of the experiment.

INTRODUCTION

Telesat, the owner and operator of Canada's domestic communications satellites, announced its Getaway Special competition in October, 1983. The contest challenged all secondary school students in Canada to come up with an idea for a space experiment. Telesat ran the competition to promote "space consciousness" and interest young Canadians in the space industry.

The closing date for the entries was December 15, 1983. Telesat received 72 entries from 290 high school students. Telesat set up a panel of judges including scientists from Canadian universities, research establishments and a NASA astronaut.

In mid January, 1984 the winner was chosen. The winning selection was submitted by two students from Ottawa who proposed the fabrication of mirrors in microgravity to compare their optical properties with similar ground-made mirrors. The students stressed the need for high-quality mirrors for such applications as lasers and telescopes which operate in the lower UV spectrum. They went on to suggest producing mirrors in the contamination-free environment of space for subsequent use in space-based telescopes. The judges were impressed by the students' presentation and were interested not only in the information to be gained in optics, but were also intrigued by what might be gathered from a metallurgical viewpoint as a by-product of the mirror making experiment.

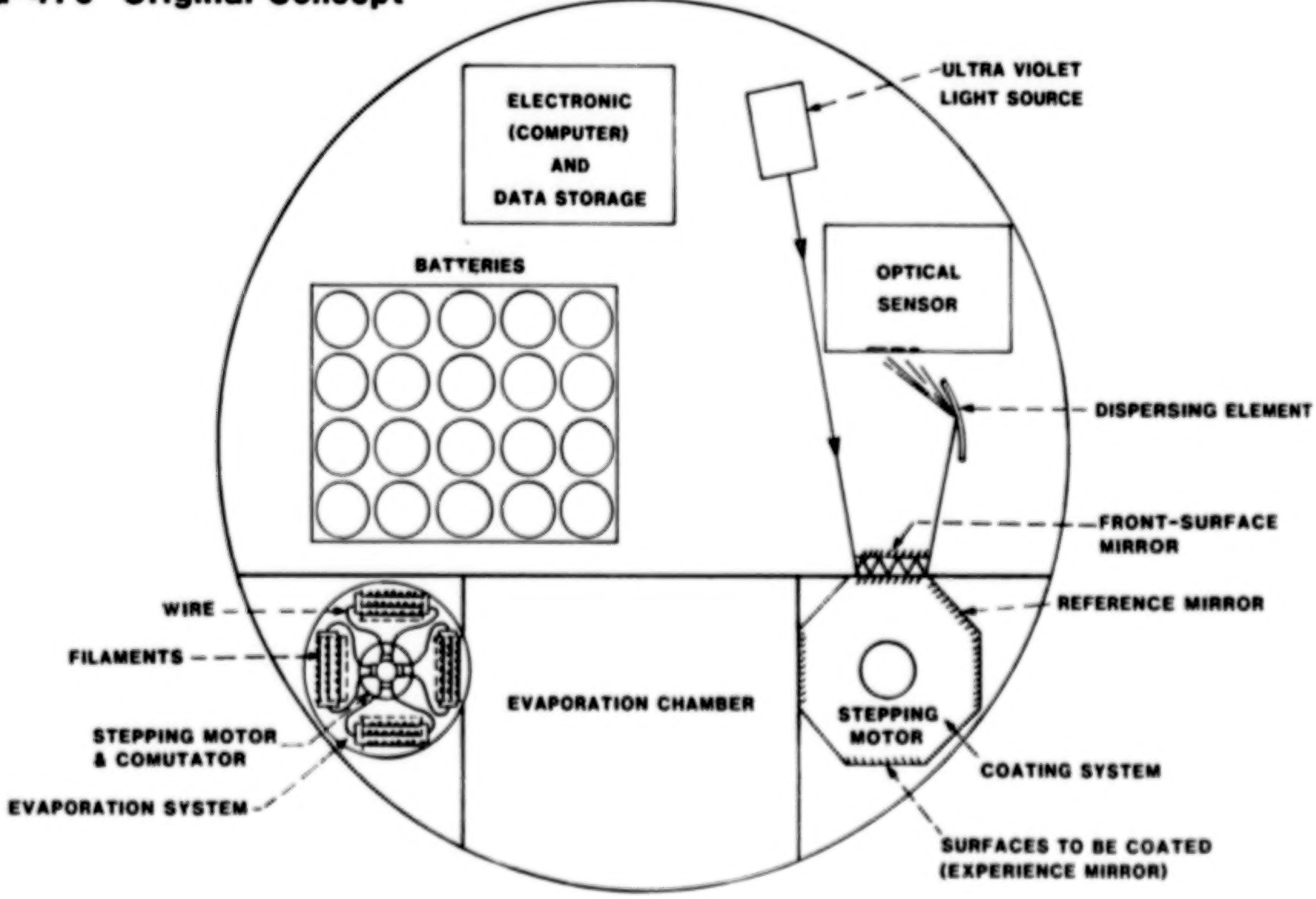
Telesat's Getaway Special was intended to fly on October 14, 1984 on the same flight as Anik D2, Telesat's eighth telecommunications satellite. This anticipated flight date gave Telesat six months to design, build, and test the GAS experiment before delivering it to NASA for flight. The evolution of the design was completed by April with the cooperation of the students and Telesat's technical advisors. The construction of the flight model, its environmental and system tests were completed by July. Due to delays in the Getaway Special program, the Telesat GAS did not fly until November 27, 1985 aboard flight 61-B.

DESIGN EVOLUTION

The design of the winning entry was rather complex (see figure 1). It employed many mechanisms, a microprocessor for control, data acquisition and storage as well as scientific instrumentation to measure reflective properties of the mirrors and to determine their degradation with time. Although experimentally a sound proposal, due to the lack of time to develop and prove such critical items as the mechanisms, optical measuring systems and data acquisition and storage systems, Telesat engineers, the students and other advisors cooperated to redefine the experiment within, cost, schedule and STS imposed constraints.

FIGURE 1

G-479 Original Concept

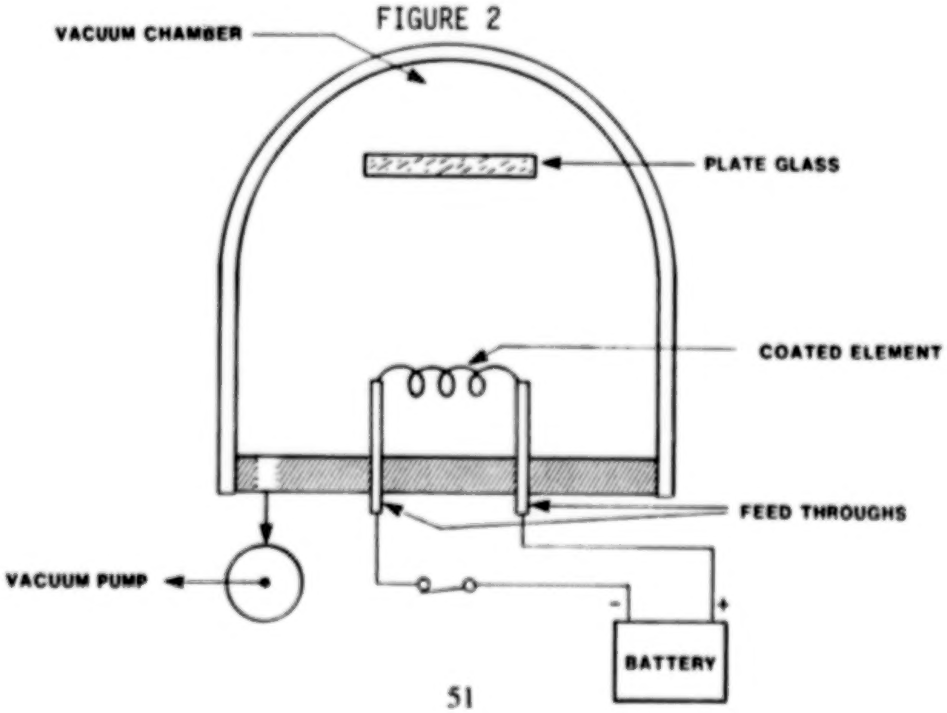


The initial phase in the development process eliminated many complex aspects of the experiment. The technique of manufacturing mirrors suggested by the high school students is widely used in the optics industry. A tungsten filament with an element, such as gold or silver, wetted to it, is placed in an evacuated chamber and powered. The current heats the filament just as a toaster filament is heated. The element vaporizes, radiating in all directions while coating everything in its path, including the required substrate, with a thin film. Quartz glass lenses were used as the substrates. Figure 2 illustrates this process.

In formulating the design of the experiment, two aspects of the shuttle environment that were kept in mind were the vacuum of its parking orbit which is in the order of two to five millitorr, and the effect of the earth's gravitational force which is in the one to two milli-G range at this altitude. A vacuum in the order of one to six microtorr is generally required to produce high-quality mirrors on earth. For most of the experiment it was decided to use the conditions readily available to see what could be done in the environment afforded in the shuttle parking orbit.

Initially there were many unknowns including the elements to be used to form the mirror reflective coatings, the temperature of vaporization of the elements, the power needed by the filament, the mass of the element to be vaporized, the size of the quartz substrate and the thickness of the coating required. To better specify the design, the unknown parameters had to be determined. The first step in this experimentation stage was to make a mirror. A 12 volt power supply was selected for simplicity. A piece of silver was wetted to a tungsten filament and was then inserted into a glass bottle. The bottle was placed in a vacuum chamber and, once evacuated, power was applied across the terminals of the filament. The amount of current consumed was recorded and used as a measure to design a power subsystem. A series of similar tests followed to optimize the filament selection and the weight of the element.

FIGURE 2



The experiment needed a means of holding the quartz substrates while taking advantage of the vacuum of space. To do this, two quartz lenses were placed at either end of a steel tube with a filament inserted between them. Holes were drilled in the tube. These holes allowed air to evacuate from the tube when the shuttle left the earth's atmosphere (the GAS cannister was open to the shuttle bay).

For elements such as sodium, that require a vacuum in the one to six microtorr range to sublimate, a sealed hourglass tube was designed. The neck of the hourglass contained the element to be vaporized, and each end of the hourglass served as the flat substrate forming the desired mirror surface. The glass tube was evacuated on earth and a filament was wrapped around the neck.

DESIGN IMPLEMENTATION

With the initial experimentation completed, the final design began in earnest. Many of the design rules used by Telesat's team of engineers are standard in the spacecraft industry: such as redundancy, safety factors and the use of conservative estimates. These rules were applied to maximize the probability of success and to avoid a single point failure. For redundancy, it was decided that two separate experiments would fly. Two power and control subsystems, two separate wire harnesses and two sets of experimental hardware made up the experiment.

The design of the steel tube to hold the quartz substrates had to be optimized. The quartz lens size was determined by what was readily available (two inch diameter) and the size of steel tube was chosen from standard stock. The steel tubes had to be baked to drive off any impurities in the steel. The tubes' lengths were maximized to fit in the GAS container vertically. The drawback of this tube system was the fact that air re-entered the tubes when the shuttle returned to earth. The mirrors started to oxidize as soon as they came in contact with air and some contamination followed. This contamination prevented the definitive study of degradation which was one of the students concerns.

The packaging for the hourglass tube was designed to absorb the vibration of launch and contain the chemically reactive sodium if the glass were to break. The size of the hourglass tube was modeled after the steel tubes. Two drawbacks to this hourglass tube were the fragility of the glass and the fact that helium permeated the glass walls degrading the vacuum over time. This made it imperative that the flight tube be manufactured and installed as late as possible in the experiments integration into the shuttle.

The placement of the filaments and the weights of the elements on them were selected by the students to achieve the desired variety of film thicknesses coating the quartz lenses. To cover the lower UV spectrum, gold, silver and aluminum were selected as elements to put on the filaments in the steel tubes. In addition to these elements, sodium was selected as it was an interesting element to study. The sodium was placed in an evacuated hourglass tube. In all, six tubes were flown: five steel tubes and one hourglass tube.

After the GAS experiment was built and tested, the students suggested a minor modification that would greatly increase the amount of scientific data that could be gathered. Following some research, inserts holding smaller samples were placed in the steel tubes along with the original quartz lenses. These samples were later examined for their metallurgical properties by performing transmission electron microscopy (TEM) tests.

The power requirements were determined by fabricating mirrors with the flight hardware and calculating the power needed by the control subsystem. One problem that the tungsten filament presented was that its resistance was very low when the filament was cold, thus drawing a lot of current. By placing a low-value, high-power resistor in series with the filament this surge of current was minimized.

For three reasons Gates lead acid "J" cells were chosen to power the experiment: 1). they met the power requirements even after derating for cold temperature and losing up to 35% capacity due to self discharge. This discharge occurs from the time the experiment is integrated at KSC until liftoff (the payload is not accessible during this time); 2). the "J" cells were selected because they were approved by NASA and had flown on previous missions; 3). they were available and affordable. Extensive tests on the cells were performed in Telesat's battery lab. The cells were subjected to many charge and discharge cycles to characterize them. These tests verified the ability of the experiment to perform under worse case conditions, such as temperature and starting with 35% depth of discharge.

The control subsystem was designed around the power and thermal constraints as well as the timing requirements determined from the initial glass bottle mirror experiment. The optimized timeline required that the mirrors be made sequentially rather than simultaneously, with a one minute gap between each mirror production. The gap between mirror fabrications allowed the electrolyte to redistribute itself in the batteries and let the structure equalize thermally. With this in mind the circuit was designed using readily available military specification parts. A separate board was made to control each experiment.

The wiring harness consisted of teflon wire and non-outgassing wire connectors. The wire was derated for use in vacuum. The fuses chosen were also selected using a vacuum derating policy. This created some concern with NASA safety experts so tests were run with the fuses in a thermal vacuum chamber to verify the safety of the wiring harness. The grounding techniques used for the harness prevented ground loops.

CONSTRUCTION TECHNIQUES

The construction techniques were along the conservative lines set out in the design phase. Where possible, the materials and parts were selected from Goddard's preferred parts list (PPL-17). Standard processes and procedures common to the spacecraft industry were adhered to. Clean room techniques were used in the handling of flight hardware.

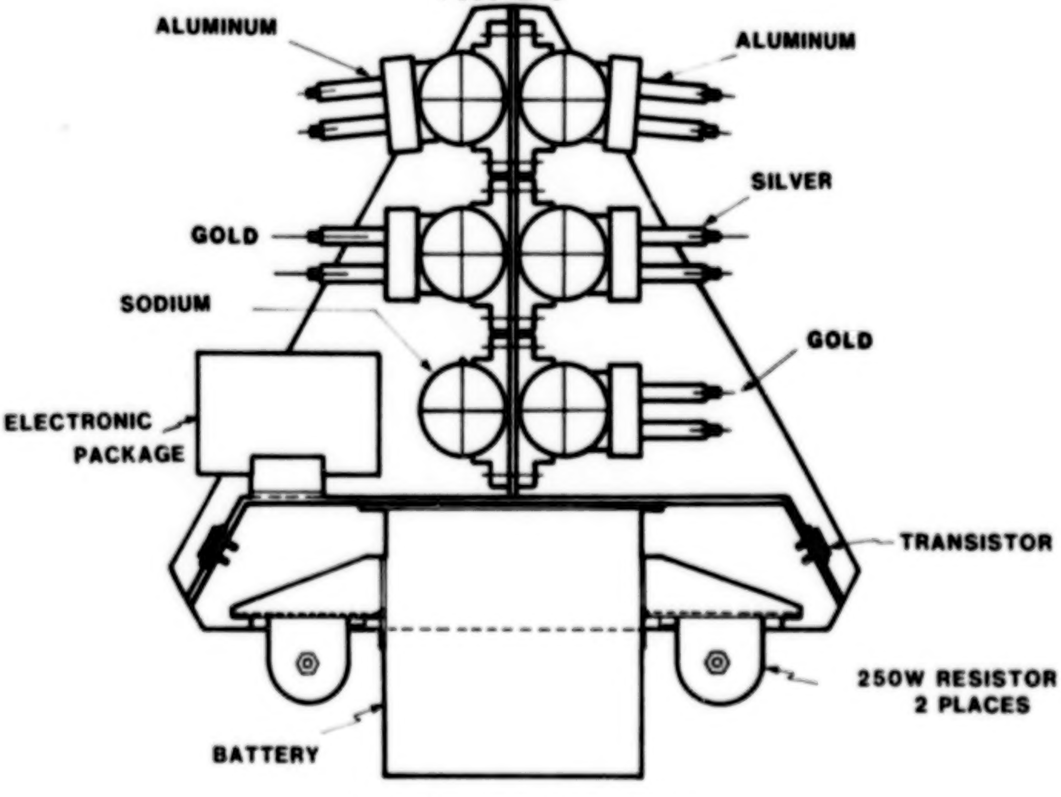
The structure (see figure 3) was made of 6061-T6 aluminum and was welded to reduce its weight and to simplify its fabrication. The structure was anodized black to equalize thermal gradients. All components such as the steel tubes and battery box were bolted to the structure using steel bolts. To ensure mechanical strength through the vibration of launch, all fasteners were secured with lockwashers and Loctite was applied.

The circuit board for the control subsystem was assembled on an anti-static mat. Heat sinks were used where necessary. The boards were conformally coated to ensure good mechanical strength, and protection from static, moisture and debris which could cause shorting of components. The circuit boards were mounted in a box which was bolted to the structure. Edge connectors carried the power and signals to the rest of the circuitry. These connectors made assembly, test and board exchange a simple task.

To avoid damage during the vibration of launch, the wiring was well secured. Tie points were spaced no more than three inches apart and tie wraps were used to secure the wires to the structure. All exposed terminals were coated with Hemoseal, an epoxy-like insulating material.

The aluminum battery box was lined with teflon to contain the corrosive battery acid in the event of a battery rupture. Gaps between the cells were packed with fibreglass insulation to absorb any possible electrolyte spillage. A gasket was used to seal the battery box to ensure that it kept its one atmosphere pressure (a NASA requirement).

FIGURE 3



VIEW LOOKING INTO CANISTER

TEST METHODOLOGY

Testing was the most important phase of the mirror experiment. As mentioned earlier, tests helped to shape the design by narrowing down parameters such as, what current was required, how the batteries would perform and how derated fuses would work. Without these preliminary tests the design would have been poorly specified. Later on, the system tests acted to qualify the experiment for flight worthiness.

The test philosophy was the same as applied by Telesat to normal space flight hardware. Everything was tested as it would be used in flight with a safety margin added. Mathematical analyses were performed on the thermal, electrical, and mechanical subsystems. The analyses were backed up with tests using more extreme than anticipated levels (temperature, voltage, vibration). The experiment's operation was verified in a thermal vacuum chamber and all tests were performed using the flight hardware.

There were several phases to the test program. The electrical subsystem was tested first. The electrical subsystem test powered the experiment as if it were in flight. Instead of making mirrors, however, electrical loads received the power in place of the flight filaments. This test verified the timing and control subsystem as well as the power subsystem. Upon completion of this sequencing test, the flight filaments were hooked up, visually inspected for flaws and then checked with an ohmmeter for continuity. Next, during the mechanical subsystem test, the experiment was vibrated to levels 1.2 times higher than those suggested by NASA in their experimenter handbook, as an added safety factor. An electrical subsystem test was again performed to ensure the correct operation of the experiment. The following stage of the test program most closely resembled the flight conditions. The experiment was activated in a thermal vacuum chamber at the worst case temperature conditions, and mirrors were fabricated. This was the last test performed prior to putting the experiment in storage to await an opening in NASA's queue.

When a flight opportunity was announced the experiment was taken out of storage and another electrical subsystem test was performed. The experiment was shipped to KSC, unpacked and inspected by Telesat engineers and the NASA project manager. As the experiment had been in storage for over a year, a new sodium tube was installed as the original tube's vacuum had probably diminished. The experiment was reassembled, then underwent an electrical subsystem test. The batteries were recharged and the Telesat GAS was then handed over to NASA, ready for flight.

As explained, the test program was quite extensive. Testing was performed at every phase of the program to ensure the correct operation of the experiment. Though not required by NASA, tests such as vibration and thermal vacuum tests, were performed to give confidence in the integrity of the experiment hardware.

TECHNICAL RESULTS ACHIEVED

The experiment was a success; mirrors were made. Of the six sets of mirrors to be manufactured, five worked. The sixth set was the hourglass type containing sodium. The neck of the glass cracked, apparently due to the vibration of launch. As discussed earlier, the vacuum achieved in the shuttle's parking orbit is not sufficient to allow the sodium to sublimate, thus sodium mirrors were not made. After the experiment was returned to the lab, a set of ground sample mirrors were made using the flight hardware in a thermal vacuum chamber as comparisons for test purposes.

A series of tests are being performed on the mirror samples. The tests are being conducted at research labs of the National Research Council of Canada, the University of Toronto, and by Litton Systems in Toronto. The testers are comparing the space-made samples with the ground-made ones. Some of the measurements being made include: reflectance measurements, polarization measurements, backscatter measurements, diffraction tests, transmission electron microscopy, scanning electron microscopy and spectroscopic analysis. The evaluation process is not yet complete. The technical reports should be available in the near future.

CONCLUSIONS

Planning and flexibility of design are the keys to a successful GAS experiment. To reduce costs and avoid bottlenecks in the program, long lead-time items were ordered at the outset. Spare parts of hard-to-get items were also purchased. The material costs were a small fraction of the budget so a few critical spare parts were purchased in order to alleviate possible problems further on in the development program.

Near the end of the construction phase it was determined that a minor modification of the steel tubes could yield much more valuable data. This modification referred to earlier, was the addition of the TEM inserts. In addition to this change, another experimental package was added to our structure taking up unused space and excess battery capacity. The extra hardware designed, built and tested by a separate research establishment, melted cadmium and allowed it to resolidify. This resolidification experiment fitted well with our mirror experiment. This flexibility late in the program extended the scope of the experiment.

To take advantage of an unexpected flight opportunity, experimenters should be ready to fly at a moment's notice. To facilitate the integration of the experiment, final preparations at KSC should be minimized.

As mentioned earlier, everything should be tested thoroughly prior to flight and done in a flight configuration. If a test results in a failure, the failure's cause should be determined, corrective action should be taken and the test should be repeated. Two problems were experienced in the Telesat GAS that illustrate these rules. First of all, the hourglass tube cracked due to the vibration of launch. This problem also occured during the vibration test. As a result of the original failure, the packaging was redesigned and an analysis was done on the vibration environment. A retest, however, was not performed due to time constraints. A price was paid for cutting corners.

The next problem occured with the experimental package added to the GAS after the mirror package was complete. As the resolidification experiment was previously tested, the system tests on the main experiment were not changed to cover the extra package. When performing the final system test at KSC a dead short was discovered in the resolidification experiment. This problem was corrected prior to flight.

We have a few suggestions for NASA to help future experimenters. It would be of great benefit to receive accurate temperature and vibration data from NASA. Telesat has launched several satellites on the shuttle, so were able to access data from these past flights. Other experimenters are generally not so fortunate. An explanation of techniques and materials for use in evacuated GAS cannisters would be useful as well. Our major complaint was NASA's inability to forecast a realistic launch schedule. It would be of great benefit to the experimenter to know, within a fixed time-frame , for example three months, when their payload would fly. This would allow the experimenter to budget his development time accordingly. On the whole, the NASA interface worked very well both at GSFC and at KSC.

The original intention of the GAS competition for Telesat was to generate interest in space studies among high school students in Canada. Right from the beginning this exercise proved successful, as was evidenced from the number of responses to the competition in the short time from its announcement to its closing date. The interest continued throughout the development of the experiment which received a considerable amount of media coverage across Canada. The Getaway Special proved to be a relatively inexpensive and effective tool to arouse the "space consciousness" of Canadians and it helped the high school students, who worked on the program, better understand the scientific method and see how a project comes together.

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PROGRESS on THE OHIO STATE UNIVERSITY GET AWAY SPECIAL G-0318: DEAP

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ABSTRACT

The Get Away Special program became a major presence at The Ohio State University with the award of GAS-0318 by the American Institute of Aeronautics and Astronautics. There are about twenty engineering researchers and students currently working on the project. GAS-0318 payload is an experimental manufacturing process known as Directional Electrostatic Accretion Process (DEAP). This high precision portable microgravity manufacturing method will revolutionize the manufacture and repair of spacecraft and space structures. The cost effectiveness of this process will be invaluable to future space development and exploration.

INTRODUCTION

Currently, NASA is planning a permanent presence in space through the development of the space station. In order to be cost effective on the economic returns from such a development, scientists and engineers must develop resourceful techniques of space utilization. One way to achieve this is to maximize productivity in space. This can be accomplished by performing production and repair in space instead of on earth. The DEAP process is one such manufacturing and repair technique which will help achieve this end.

This paper presents a summary of the preliminary design of the experiment and its major subsystems combined with a discussion of the process performed by each subsystem. Some of the major subsystems discussed include the furnace, containment structure, small orifice device, directional controller, target and accreation process. In the design of this payload, a general purpose graphics oriented interactive finite element system is utilized. Final drawings of the subsystems are obtained from a computer aided design system. Each subsystem will be separately bench tested to verify compliance with the

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design requirements.

THE DEAP METHOD

Researchers have been investigating possible space manufacturing techniques for the past two decades. Most manufacturing and construction techniques studied to date are directed at large space structures. The DEAP unit concentrates on small scale manufacturing and repair capabilities.

DEAP requires five material processing steps. Each step has associated with it one or more experimental subsystems that perform each processing step. The five processing steps are;

- Bulk material liquefaction,
- Droplet formation and charging,
- Droplet directional guidence,
- Target surface accreation,
- Three dimensional build-up.

Bulk material liquefaction:

Producing or repairing parts and structures through the DEAP method requires that a reasonably pure material be utilized. That is, microstructural inclusions which degrade material purity be minimized to preclude clogging of the DEAP unit and failure to guide and accrete the material. Liquefaction is accomplished by the subsystem known as the furnace.

The current furnace design consists of an electrical resistance heater wrapped around a cylinder which houses the bulk material. Since the furnace consumes most of the power required to operate the experiment, battery requirements are substantially impacted by the amount of energy required to liquify the material. Thus, material selection will be limited by this power requirement. An electronically controlled displacement pump will produce the molten flow delivered to the small orifice device.

Droplet formation and charging:

The small orifice device collects the supply of molten flow in a chamber which supplies a convergent channel. This channel, or nozzle, is responsible for producing the droplets which will be accreted to the target surface. In this unit, two separate nozzles will be utilized and each will have a separate droplet directional controller.

Droplet directional guidence:

Since each droplet carries a small charge, electrostatic fields are used to impart accelerations to each droplet, thereby permitting directional control. Because it is exteremely important to accurately guide each droplet, separate deflection systems will be applied at each nozzle. Accurate directional control permits the production of a variety of geometric shapes with considerable dimensional precision in the unfinished condition. Thus, finishing work is largely unnecessary and can be avoided.

Target surface accretion:

Droplets are deposited on the target surface in a precise manner. As the droplets are deposited, two important phenomena must occur; surface wetting and solidification. Surface wetting must occur or the material droplets will simply rebound or be displaced by newly arriving droplets. Solidification of the wetted droplets must be rapid upon contact with the target or splattering and loss of dimensional tolerance is likely to result.

The target consists of a muliposition disc plate with individual target plates attached. Separate targets of different selected materials will be tested for accretion properties. One aspect of this experiment is to determine which materials yield desireable accretion properties such as surface wetting and rapid solidification.

Three dimensional build-up:

To date, the accretion process is largely untried. Accretion layering is an even greater unknown process. Layering, or three dimensional build-up, must be achieved to produce a complete part or to repair a damaged structure.

Additional Subsystems:

There are two additional subsystems which are important to the success of the experiment. They are the containment structure and the microprocessor.

The containment structure houses the small orifice device, the directional controller and the target. This structure consists of a cylindrical pressure vessel which is evacuated to the space environment such that the vacumn of space will be simulated within the containment vessel. The accretion process will be contained within the containment vessel.

The microprocessor is responsible for operating the experiment from the system level. Once the "on" signal is received from the mission specialist, the microprocessor will run the experiment and then shut down.

COST EFFECTIVENESS

The cost effectiveness of the DEAP method is without doubt an important aspect. There are three attributes to this method which account for this important criteria:

- Bulk material packaging,
- High precision tolerance finish,
- Transportability.

Bulk material packaging:

Payload bay packaging has limited most space launches in their ability to boost material into space. However, if parts and structures were manufactured and assembled in orbit, then only bulk material need be delivered to orbit. This ability would ease packaging constraints and improve the efficiency of delivering material to orbit for constructive use. The DEAP method utilizes bulk material as the process working material.

High precision tolerance finish:

Due to the accurately controlled placement of material droplets, the DEAP method inherently produces a high precision finish. There is little or no need for finishing work which results in potentially huge cost savings. Also, material properties will retain high quality and reproducibility as well.

Transportability:

Since the DEAP unit is a relatively simple machine, it can vary in size and complexity depending on the intended product or use. Large units could be placed in stationary orbits for space structure production while small units could be transported about for special assignments. In fact, hand-held DEAP units could be designed for mobile repair of craft and structures.

DEVELOPMENT and VERIFICATION

The design development and layout of this experiment are being performed on an IBM/370 and a VAX/11-780 with CADAM and GIFTS systems. The CADAM models are utilized to perform part of the finite element analysis to verify compliance with design requirements. Eventually, each subsystem will be build and bench tested to verify the performance.

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NUSAT Update

By Charles A. Bonsall

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This paper presents, in general terms, the results of the experiments with NUSAT I. These include what has been learned about the strengths of the original design, as well as improvements being incorporated into NUSAT II, which should be of interest to designers of future Get Away Special ejected satellites. This paper also presents an account of the formation of the Center for AeroSpace Technology (CAST) at Weber State College, which grew out of the NUSAT project, and some potential applications and markets for inexpensive, low orbit satellites which CAST has explored.

THE GOALS OF THE NUSAT I PROJECT

NUSAT I was a small, 105 pound satellite ejected from the orbiter, Challenger, shortly after the launch of mission 51B on April 29, 1985. The principal experiment on board NUSAT I was an L-band measurement system to determine the vertical radiation pattern of air traffic control radar antennas. This information would then be used to optimize the coverage volume of these radars.

The NUSAT project was organized with three stated goals:

- to provide an exciting, real life educational experience for students;
- to test the Get Away Special (GAS) canister as a platform for ejecting small satellites into independent orbit; and
- to demonstrate a technique for measuring the vertical radiation patterns of large vertical aperture antennas.

Some implied goals were:

- to test the effectiveness of an ad hoc, volunteer organization comprised of individuals from academia, industry and government;
- to enhance awareness of Northern Utah as a center of aerospace activity; and
- to facilitate networking of aerospace technologists.

NUSAT I EXPERIMENT RESULTS

Contact was established with NUSAT I a few days after launch and continued until July 15, 1985. However, communications during this period were characterized by low reliability. After a period of optimizing the ground station facilities and improving operator proficiency, it became clear that there was at least one problem on board the satellite. Many possibilities were considered including antenna orientation, solar cell or battery failure, interference, abnormal temperatures, and others, most of which could only be determined by the acquisition of sensor data. Eventually this data was obtained and indicated that the system temperatures and voltages were normal. Since only very short programs could be uploaded successfully, several other experiments could not be completed before all contact was lost in July.

Following a thorough recheck of the ground station it was assumed that the satellite had failed. Nevertheless, routine attempts to communicate with the satellite continued with no success. Ironically, during the early evening of November 23, 1985, while several participants were gathering to prepare a final, pessimistic report to the Federal Aviation Administration project coordinator, a half-hearted attempt to contact the satellite was successful! A number of new experiments were formulated based upon the observed system behavior and recently enhanced capabilities of the ground station, such as doppler compensation under software control. For example, it was noticed that the ground station room was unusually cold the night of reacquisition and the possibility of frequency drift on the satellite was considered. Eventually, it was determined that the modem clock on board NUSAT I had shifted and was compensated for by adjusting the ground station system.

Since last November, communications with NUSAT I have been very reliable, allowing routine uploads of long programs and successful downloads of large masses of data. One common operation has been the downloading of sensor data collected at various increments during an entire orbit. This has allowed study of the behavior of the power system while illuminated and shaded, as well as, analysis of platform attitude using the light sensor data. Another frequent operation has been the collecting of L-Band signal data while using unique interrogation modes from Federal Aviation Administration and Air National Guard radars in Utah. In addition, several experiments have been conducted with: Montana State University, an astronomer in Texas, amateur radio operators, even successful communications with a handheld transceiver!

The results of over a year of operation and experimentation with NUSAT I support the following conclusions:

1. The GAS canister is an excellent, low cost, vehicle for injecting a small satellite into low altitude, circular orbits. NUSAT I was ejected at an altitude of 360 km which had decayed to 305 km by June 1986. The orbit eccentricity was very low with a difference between apogee and perigee of about 8 km at that time.

2. It is possible to achieve reliable open-loop tracking of low orbit satellites using very inexpensive equipment operated by relatively inexperienced students. But an onboard beacon would simplify acquisition and tracking.

3. The enhanced flexibility permitted by the totally programmable philosophy implemented in NUSAT I is invaluable. Only the communications protocol, timing functions, security and fail-safe routines are in firmware on the satellite. All operational programs are uploaded from the ground station, which has allowed operational changes and experiments unthought of prior to launch.

4. Physical accessibility to internal components is an important consideration in the mechanical design of a small, but complex, satellite. Several post-assembly repairs and changes to NUSAT I were very difficult to accomplish.

5. Attitude determination by light sensors alone is a very complex, inaccurate process, especially when the spectral and directional characteristics of the sensors are not thoroughly measured prior to launch....

6. The time domain pulse discrimination technique used in the Federal Aviation Administration experiment on NUSAT I may be inadequate for use in the dense L-Band pulse environment over the United States and Europe.

NUSAT II DESIGN IMPROVEMENTS

A number of changes are being incorporated into the design, construction and operation of NUSAT II and subsequent satellites being planned by the Center for Aero-Space Technology. Some of these changes are influenced by NUSAT I experience, others are due to the availability of resources and devices not available at the time of NUSAT I's design and construction. These improvements include:

1. A full-time, low duty cycle Morse code telemetry beacon. The transmissions will contain spacecraft environmental and system parameter data which can be received by interested parties around the globe without unique equipment or knowledge. This beacon, combined with a high gain synthetic aperture antenna system on the ground, will enhance acquisition and tracking with less precise orbit predictions than those required for NUSAT I operations.

2. System redundancy. The availability of more powerful computers and larger memories requiring less current permit designs including completely redundant computers, expanded memory and dual communications systems. In addition, two isolated battery packs will be installed.

3. A cylindrical form. This will enclose a greater volume, simplify accessibility during integration and testing, increase solar panel/antenna area and enhance attitude control with more flexibility for changing moments.

4. An improved software communications protocol. A system employing error correcting codes, packet transmissions, etc., will be used to improve communications reliability under low signal-to-noise conditions.

5. An enhanced attitude measurement/control system which will increase the usefulness of presently planned experiments and provide experience and data for future satellite systems. This system will include optical and television sensors, magnetometers and magnetic torque rods.

6. Support for other experiments. NUSAT II will have sufficient volume, power and control to support additional experiments.

7. The Federal Aviation Administration L-Band system will include the following improvements:

   - Two superheterodyne receivers instead of the present six TRF receivers. This will reduce power drain and increase system stability and flexibility.

   - A frequency domain pulse discrimination technique using FFT's. This will improve operation in dense RF pulse environments.

   - Greater flexibility in antenna directional control achieved with a phased array antenna and/or selective use of attitude controlled gain antennas.

8. And, finally, a system and philosophy of project management that includes closer tracking and reporting of sub-system progress, uniform documentation standards, more frequent design reviews and closer coordination with the senior projects program.

FORMATION OF THE CENTER FOR AEROSPACE TECHNOLOGY

Following the successful design, construction, launch and operation of NUSAT I, it became apparent that many individuals wanted to continue their participation in similar enterprises. In addition, Weber State College experienced increased public interest and support, greater success recruiting high quality matriculants interested in aerospace technology and more success placing graduates in the aerospace industry. Therefore, several individuals who had been members of the NUSAT Executive Committee, and a few new participants, formed the Center for Aero-Space Technology at Weber State College.

The following is the Statement of Purpose and Goals of the Center for Aero-Space Technology:

"The Center for Aero-Space Technology is a non-profit organization of individuals from industry, education and government in association with Weber State College. The purpose of the Center is to propose, solicit, design and manufacture useful aero-space experiments, devices or systems, or to support similar enterprises in other Utah schools and organizations.

"The goals of the Center are:

- **to generate significant, practical and realistic technical experiences for students;**
- **to provide a local center for aero-space technologists to connect with others of similar interests, share their expertise with students and associates, and achieve other personal goals;**
- **to create an environment in Northern Utah which will support aero-space industries;**
- **and, to facilitate public aerospace education in Utah.**

"It is envisioned that future projects will be modeled after the NUSAT I project, in which its goals were achieved through a combination of student and volunteer efforts, donated resources and contracts with other organizations."

The Center for Aero-Space Technology is governed by a Board of Directors from the college, industry and government. A larger group of aerospace professionals serve as student group advisors. And the production teams are formed of senior project, and other, student groups working with faculty members and advisors to do the actual design, manufacturing and testing of systems.

Presently the Center employs a full-time director, a part-time consultant from the faculty and several part-time student operators and researchers. Funding for the Center comes from several sources including: a grant from the Utah State Board of Economic Development; a third contract with the Federal Aviation Administration; and a matching grant from Weber State College. Contracts with the Center are administered by the Director of Sponsored Projects at Weber State College.

The Center for Aero-Space Technology, as part of the Western Space Consortium, including Weber State College, Montana State University, University of Idaho and several corporations, has applied for a NASA grant under the Centers for Commercial Development of Space program. The Center has been invited to participate in two other consortiums one of which has received, the other has applied for, a similar NASA grant. The author is chairman of a sub-committee of the Satellite Operators and Users Technical Committee which is investigating a potential application for small low orbit satellites. Other members of the Board of Directors are pursuing similar projects within their own corporations, government agencies, SDIO, etc. The Center is continuously receiving communications from sources as varied as universities in Pakistan, government agencies in the United Kingdom, corporations in Japan, as well as, individuals, corporations, educators and government agencies in the United States. Some proposals have been beyond our capabilities and we have referred them to other organizations and others have been of questionable value, but several are being pursued as future projects for the Center.

LOW ORBIT SATELLITE APPLICATIONS

There are many potential applications requiring small, low orbit satellites. Some are in the area of communications and control, such as collecting environmental sensor and position/movement data from remote locations, remote management of power and irrigation system resources and many customized message delivery systems. A large variety of space-based sensor platforms are needed and a vast number of military projects require these satellites. A great deal of research is needed to specify and invent: the optimum communications systems; inexpensive and simple attitude determination and control systems; multi-spectrum sensors; materials testing systems for the low orbit environment; artificial intelligence for auto-operation of spacecraft systems; and many more....

For example, the Center is working with the Federal Communications Commission, the Satellite Operators and Users Technical Committee, and several colleges and corporations to develop and deploy a low orbit system to locate sources of interference with geo-stationary communications satellites. A similar system can be used to improve tracking and locating systems presently employing a meteorology satellite.

The Center is also pursuing several projects that are of interest to the Strategic Defense Initiative Organization.

The opportunities to improve existing systems and develop new systems are endless. There is so much work to be done that no individual organization needs to fear that others will steal all the opportunities.

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SOPHISTICATED SOFTWARE SYSTEMS FOR SMALL SELF-CONTAINED SPACE SHUTTLE PAYLOAD G285

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ABSTRACT

The increasing development of small microprocessor systems has allowed the use of more advanced software in the area of control systems. This paper discusses the development of software for small Space Shuttle Getaway Special Project payloads using payload G285 as a case example. The development process behind a space related software package (as in any software package) is a major factor. The design process for G285 is discussed in some detail along with the general scheme behind data acquition and thermal environmental control for a space related payload. Additionally, key concepts in a software system concern the implementation of redundant systems, error detection, and error response. All of these factors are discussed within this paper.

INTRODUCTION

The University of Colorado's Getaway Special Program began in the Spring of 1984 when a group of students began to solicit the University community for experiment ideas applicable for investigation aboard NASA's space shuttle orbiters. Three experiments were selected for their feesability, applicability to current space operation work, and for their contribution to scientific advancement within the University.

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The first experiment, a biological experiment, will study the theory of geotropism as it applies to a small fungus called phycomyces. Growth of this organism will be initiated several days prior to launch via a small preprogrammed clock. The fungus will be photographed prior to launch and during launch using a small camera. The second experiment deals with studies of the separation of gases and liquids in a zero-gravity environment. This experiment, utilizing a small centrifuge to separate the gasses and liquids, will be started within 24 hours after achieving orbit. The activity within the centrifuge will be recorded using a camera. The third experiment will examine the phenomenon of shuttle glow around the orbiter's tail section using an ultraviolet spectrometer. The spectrometer will be able to view the tail via an intricate mirror assembly constructed at the top of the payload. A Motorized Door Assembly (MDA) allows view outside the cannister. A fourth experiment was later added. This will use eight thermal sensors positioned throughout the cannister to examine the temperature fluctuations within an open GAS cannister.

MISSION SEQUENCE

Controlling all of the sybsystems with the exception of the phycomyces experiment (this is a completely isolated experiment) is a small National Semiconductor (NSC) MA2000 series microprocessor component system utilizing a Z80 instruction set as a base for all software. All data will be stored in bubble memory totaling 0.5 Megabytes for retrieval post-flight (see Figure 1 for data allocation of various experiments). A general timing sequence is needed for payload operation and this is provided by an MM58174A Microprocessor-compatible real-time clock external to the microprocessor.

Within 24 hours of achieving orbit, the astronauts will flip one of the three GCD switches which will activate the G285 payload. This will initiate internal power thus causing the microprocessor to bootstrap. A resistive heater will also be turned on near the microprocessor to help alleviate possible microprocessor problems due to cold temperatures. The power to the bubble memory will be turned on and a header written to the top section of memory to indicate a successful initiation of microprocessor control. All thermal sensors (eight) will be checked and data stored in the header section of the bubble memory for post-flight data analysis as to the initial characteristics of the cannister.

Once initialization has completed, the microprocessor will initiate power to the fluids experiment and a small camera. The microprocessor will be in complete control of the camera, sending a pulse to the device to take each picture. Approximately 300 pictures will be taken over the period of the next two hours at varying but predefined intervals. For each picture taken, three bytes of data will be stored that contain a time tag consisting of hours (0-??), minutes (0-59), and seconds (0-59) since payload activation by the astronauts. The clock will be read for each time tag and compared with the initial time of power up (stored within a main program variable and also within the header of the bubble memory). These 300 time tags stored over a period of two hours will actually be much greater then needed by fluids experiment specifications but will enable microprocessor personnel evaluate the computer's response to the severe environment and will also provide the best time correlation for data analysis. Temperature data will also be stored at a rate of eight samples (one sample per sensor) each minute.

CATEGORY	BYTES	FRAMES	%TOTAL
FLUIDS EXPERIMENT	**1900**	**10**	**0.36%**
CAMERA TIME TAGS	900	-----	0.17%
THERMAL DATA	960	-----	0.18%
BLOCK HEADER TIME TAGS	0	-----	0.00%
STATUS FLAGS	20	-----	0.004%
SYNC WORDS	10	-----	0.002%
UNUSED	10	-----	0.002%
INTER-EXPERIMENT GAP	**57**	-----	**0.01%**
SPECTROMETER EXP.	**522310**	**2749**	**99.62%**
SYNC WORDS	2749	-----	0.52%
STATUS FLAGS	5498	-----	1.05%
TIME TAGS	8247	-----	1.57%
THERMAL DATA	10996	-----	2.10%
EXPERIMENT DATA	494820	-----	94.38%
BUBBLE MEM. HEADER	**21**	-----	**0.004%**
TIME TAG	10	-----	0.002%
SYNC	1	-----	<0.001%
STATUS FLAGS	2	-----	<0.001%
THERMAL DATA	8	-----	0.002%
TOTAL	**524288**	-----	**100.00%**

Figure 1. *Data allocation for project G285*

At the conclusion of the two hours, the fluids experiment will be powered off and a sequence of bytes (i.e. 255 values) will be written to the bubble memory to indicate a gap in data prior to initiation of the next experiment. Following this, the spectrometer will be powered up and a pressure sensor will be checked to verify a safe pressure level. (The inside of the cannister will be pressurized to approximately 1 atm of argon. This is to avoid problems with corona discharge caused by high voltage in vacuum or near vacuum environments. The entire spectrometer will be within this sealed container with a field of view out through a small quartz window. In the event that the pressure drops to approximately 10 torr, corona discharge will take place. To avoid this problem, the microprocessor will automatically shut off high voltage power at approximately 50 torr.) Upon initiation of power to the high voltage power supply, the microprocessor will initiate an ultraviolet region wavelength scan with the MDA closed (used for calibration purposes).

Data in the form of data numbers (0 to 255) will be read from a Pulse Amplification Detector (PAD) counter. This counter is a ripple bit counter and as such, the line from the PAD to the counter must be disabled prior to being read by the microprocessor (see figure 2). Every 1/3 second, the microprocessor will disable the line, read the counter, reset the counter to zero, and then enable the line between the PAD and counter. A ninth bit of the counter is also checked on each read. This is an overflow bit that is latched upon a carry out of the eighth and most significant bit of the counter. In the event of a data overflow, a value of 255 will be written to memory to help post-flight data analysis.

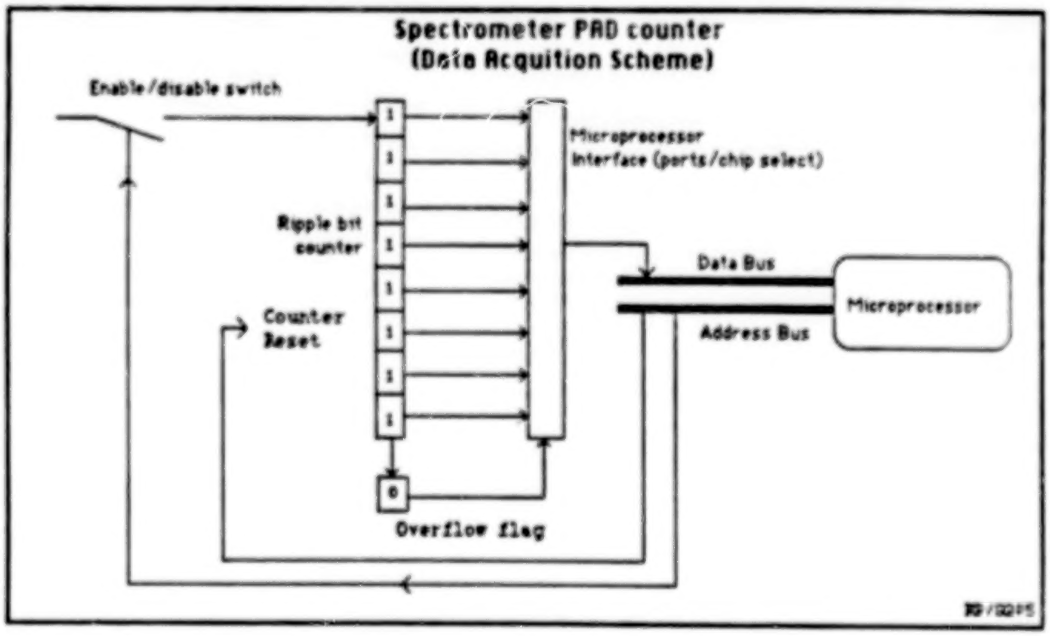

Figure 2. *Data acquition scheme*

After each data sample is read, the grating drive of the spectrometer will be stepped. A total of 180 grating positions will be used (to allow for a scan time of approximately 1 minute). After each complete grating drive scan, the mirror (constructed outside the quartz window) will be moved one position by activating a worm gear motor controlled by the microprocessor. This will be repeated twelve times to allow for twelve different mirror positions. In this way, a complete scan across the tail section is achieved. (See figure 3 on pointing angles.) A photodiod is used as a Bright Object Sensor (BOS). This incorporates a field of view greater than that of the spectrometer to detect of the emergence of any bright object into the field of view (i.e. Sun, Moon, Earth, etc.). In the event of a triggering of the BOS, the power to the high voltage power supply is disabled and an interrupt is sent to the microprocessor.

Thermal data is also collected during the spectrometer portion of the mission at a rate of four samples a minute. This will result in a complete thermal data resolution of at least two minutes per sensor.

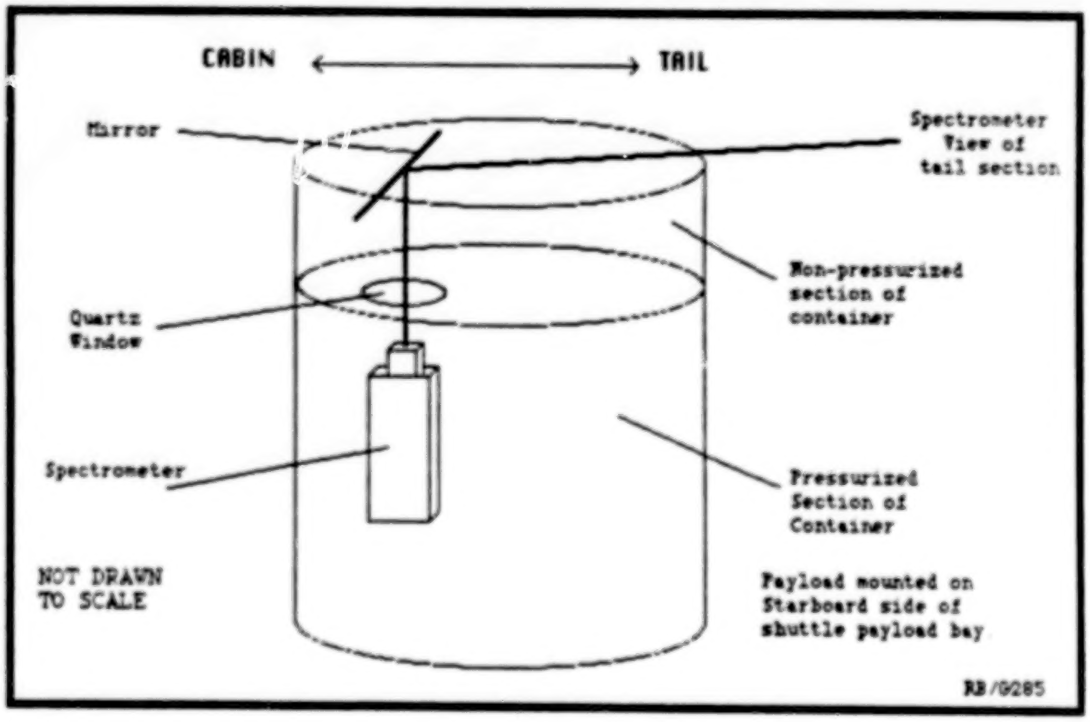
CABIN
TAIL
Mirror
Spectrometer View of tail section
Non-pressurized section of container
Quartz Window
Spectrometer
Pressurized Section of Container
NOT DRAWN TO SCALE
Payload mounted on Starboard side of shuttle payload bay
RB/9285

Figure 3. *Spectrometer pointing angle*

TELEMETRY FORMATTING

All data gathered during the mission, will be formatted into 190 byte blocks (see figure 4 on data block format). This number was chosen to allow for an approximate one minute resolution of data frame during the spectrometer portion of the mission. Each data frame consists of a one byte sync code, three bytes of time tag, two bytes of status flags, four bytes of temperature data, and 180 bytes of instrument data. This allows for a 94.7 percent raw data content which meets all mission requirements. During the fluids portion of the experiment, this 180 bytes consists of time tags (3 bytes) and temperature data to give a resolution of approximately 12 minutes per frame. During the spectrometer portion, the data frames are collected in groups of 12 (corresponding with the 12 mirror positions) to form a major frame (or block) consisting of 2160 bytes of raw data for each 2280 bytes of data stored. All data is buffered in RAM in 190 byte segments and then downloaded to bubble memory.

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Early in the mission, a variable length data format scheme was considered. This incorporates a block counter indicating the amount of data stored in each frame. This number is then inserted into the block to aid in post-flight data formatting. The variable length format, however, has specific drawbacks. Post-flight data formatting will rely on the fact that the block counter is correct (i.e. not getting corrupted) and in a particular position of the block. To add safety checks, one would need to add long sync words (longer than is needed in a fixed length version) to the telemetry frame, thus diminishing the amount of data storage available to science data. For this reason, the variable length data format philosophy was discarded and a fixed length format was selected for its structure and time oriented basis (the frame structure). The 0.5 Megabyte memory will allow for a total of 2759 frames with a total of 78 bytes left over. These 78 bytes are used up in the initialization header and the inter-experiment gap written to the bubble memory between the fluids experiment and the spectrometer experiment.

The fixed length format also helps in developing plans for post-flight data formatting. Upon conclusion of the mission, all data will be downloaded to an HP64000 computer system and from there downloaded to a VAX 11/780 computer. Here all data formatting will be done and data inserted into the appropriate data bases. Utilizing the fixed length format, the 190 bytes can be masked and all data stripped out quite easily. In addition, an added sync detect can be put into the system by triggering sync not only on the fixed one byte sync word but on the unused bits of the minutes and seconds fields of the time tags (2 most significant bits). This increases the ability to perform redundant error checking post-flight.

REDUNDANCY OF SYSTEMS

Early in the planning for G285, the subject of redundant microprocessors was discussed. The dual microprocessor system was later discarded since the development of such a system created more problems than would be solved by this method (i.e. handshaking, "who is slave and who is master", etc.). Redundant microprocessors would however be of great use in larger systems in which failure of the payload could have disasterous effects. In the case of G285, the payload just did not fall into this category.

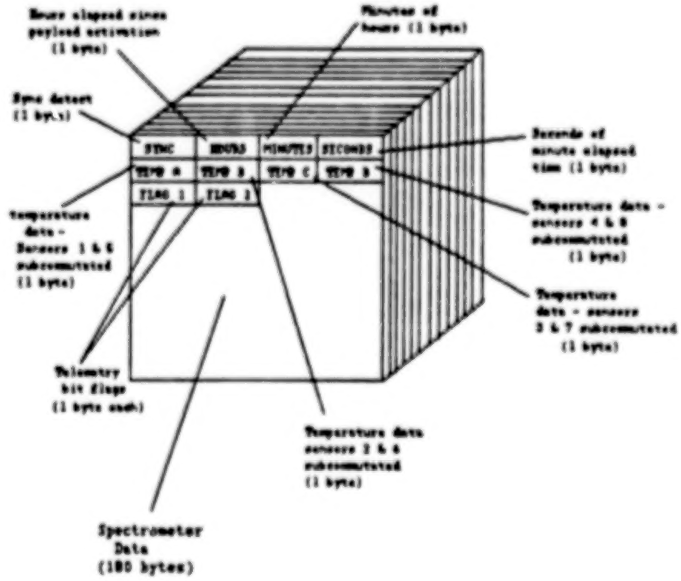
Hours elapsed since payload activation (1 byte)
Minutes of hours (1 byte)
Sync detect (1 byte)
SYNC
HOURS
MINUTES
SECONDS
TEMP A
TEMP B
TEMP C
TEMP D
FLAG 1
FLAG 2
Seconds of minute elapsed time (1 byte)
Temperature data - Sensors 1 & 5 subcommutated (1 byte)
Temperature data - sensors 4 & 8 subcommutated (1 byte)
Temperature data - sensors 3 & 7 subcommutated (1 byte)
Telemetry bit flags (1 byte each)
Temperature data sensors 2 & 6 subcommutated (1 byte)
Spectrometer Data (180 bytes)

Figure 4. *G285 Data block format*

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Some redundancy, however, was built into the software and hardware for project G285. In the case of the BOS, a hardware interrupt will disable power to the high voltage power supply. A BOS trigger will also cause the microprocessor to enter an interrupt service routine setting a software flag to true (BOS trigger has been activated). Thus the microprocessor vote will be in favor of turning off the power to the high voltage power supply. It takes only one vote to shut off the high voltage power supply but requires two votes to turn it back on. This is to protect against failure in the system causing the high voltage to be on during sunlight (This could cause a burn-out in the PMT tube.) A similar scheme is used with the pressure sensor to protect against corona discharge.

A SOFTWARE DESIGN PROCESS

1. **EXPERIMENT SELECTION**
   All experiments are selected and defined
2. **DATA REQUIREMENTS SUBMITTED**
   Experiment principle investigators submit requests for data storage allocation
3. **DATA STORAGE ALLOCATION**
   Data storage manager allocates data storage as per experiment needs and availability
4. **EXPERIMENTS DEFINITION COMPLETE**
   Principle investigators complete list of experiment requirements and definitions and construction of payload begins
5. **PRELIMINARY DIAGRAMMING OF SOFTWARE NEEDS (includes data acquition and commanding methods)**
   This may appear in the form of flow charts, technical reports, diagrams, graphs, etc
6. **INITIAL BREAKDOWN OF MODULES NEEDED (includes hardware needs)**
   Hardware and software abilities are both taken into consideration. The entire software package outlined in step 5 is broken down into small modules
7. **BEGIN CODING OF VARIOUS MODULES (dividing responsibilities among various team members)**
   This section includes all documention of code, module testing, and documentation in terms of configuration reports. If the above 6 steps were performed well, this should proceed rather smoothly
8. **INTEGRATION OF PAYLOAD SOFTWARE (includes extensive testing)**
   Much time should be spent on this area
9. **FINAL INTEGRATION AND SOFTWARE RELEASE**

Figure 5. *GAS Software Development scheme*

Redundancy is also built into the thermal environmental control system. This consists of three resister heaters placed at strategic locations throughout the cannister. A temperature sensor is placed next to the heater to provide data to the microprocessor for imputing into the telemetry frame for post-flight data analysis. A second temperature sensor is set next to the first to control the heater. This simple circuit operates under the simple philosophy of "colder temperature yields higher heat output". In the event of a heater runaway, the microprocessor will disable the power line to the heater.

DEVELOPMENT OF A SOFTWARE SYSTEM

As in any software system developed for flight or ground use, the development process is a vital process. All hardware requirements need to be defined completely (or close to completely) before software work begins. This delaying action actually saves time in that it keeps a group from proceeding down many wrong roads. A simple diagram of a development process for a small shuttle payload is given in figure 5. The project starts out with documentation and diagrams depicting exactly what is required of the software. This must then be examined within the whole context of the payload. How does a particular piece of software relate to the entire payload? This question must be answered at every step in the development process.

The development environment in which the programmer or engineer works must be kept organized. A software configuration process (complete with paperwork filled out on each routine completed or changed) is a definite MUST especially in systems in which many people are doing the coding.

**ALL SOFTWARE CHANGES MUST BE DOCUMENTED
BOTH INTERNALLY TO THE CODE AND EXTERNALLY
IN CONFIGURATION REPORTS**

Work should NEVER be performed directly on a released routine (i.e. in the event that some change is being made to a previously released routine). A separate copy should be made and extensively tested before being submitted for release. Backup tape copies and paper copies should be made as needed or as specified by the software manager. In all, a sense of organization is necessary. Disorganization will lead to mistakes and bugs.

The choice of a language is always a question that is discussed extensively in developing any software system. For project G285, the language being used exclusively is Z80 assembly. The software is developed on a VAX 11/780 using a Z80 assembler made for interface with an HP64000 computer. The software is downloaded to the HP64000 using normal computer network lines and then downloaded from the HP64000 to the flight microprocessor through RS-232 standard interfaces. Many computers (the HP64000 included) have cross-compilers that enable programmers to program in languages such as C or pascal and then convert the source code to Z80 (or some other instruction set). For project G285, it was felt that writing the code in Z80 directly would allow the programmer more ease and flexibility to do exactly what was required.

CONCLUSION

The increasing development of software systems for small microprocessors is causing an ever increasing complexity of jobs being delegated to small control systems. Computer scientists and engineers are developing the skill of putting into software what had been put into hardware only ten years ago (the programmer free to utilize many aspects and features of the software involved). In this way, more complex systems can be developed for both space and ground related software systems. The Getaway Special Project, with its great diversity, becomes a magnificant test bed for the programmer to develop sophisticated software. However, as in any project, the programmer must be driven by the ultimate goal – to develop a sophisticated software system and at the same time, achieve maximum simplicity.

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A SYSTEMS-LEVEL PERFORMANCE HISTORY OF GET AWAY SPECIALS AFTER 25 SPACE SHUTTLE MISSIONS

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This paper summarizes the results of a thorough performance study of Get Away Special (GAS) payloads that was conducted in 1986. During the study, a complete list of standard and non-standard GAS payloads vs. Shuttle mission was constructed, including specific titles for the experiments in each canister. A broad data base for each canister and each experiment was then compiled. Performance results were then obtained for all but a few experiments. The canisters and experiments were subsequently categorized according to the degree of experiment success. For those experiments that experienced failures or anomalies, several correlations and generalizations were extracted from individual subsystem performance data. Recommendations are made which may enhance the success and performance of future GAS payloads.

INTRODUCTION

This report summarizes the results of general systems-level performance review the GAS payloads launched to date. The study was started in early 1986 (February) and continued for six months on a part time basis. Initially, the author was merely constructing a complete list of GAS experiments for each Shuttle mission, since one did not exist anywhere else. This list was to be used by student GAS experimenters at Utah State University as a mechanism for understanding what others were doing in the field as well as a tool for stimulating thought relevant to their own experiments.

However, soon after the search for input data began, it became apparent that many GAS experiments experienced severe troubles during their mission. Some GAS canisters didn't turn on, others turned on at the wrong time, and numerous individual experiments inside the cans came back to earth with little or no meaningful data. The author decided to complete the GAS payloads list and then study the array of failures and problems that many encountered. Such analysis would augment the basic GAS payloads list with performance summaries and would also provide an opportunity to step back during the break in Shuttle activity and reflect on the GAS performance record after the first 25 Shuttle missions. Some of these results are surprising and somewhat alarming!

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THE GAS CANISTER MANIFEST HISTORY

Prior to conducting a systematic study of GAS experiment results, a complete list of launched GAS canisters was required. At the start of this study, 25 Shuttle missions had been launched, including the ill-fated last one, STS 51-L. Unfortunately, this number will remain 25 for at least until early 1988.

A complete list of all standard NASA GSFC GAS canisters launched to date was available from Mariann Albjerg at NASA JSC. These canisters are tracked by the reservation number, such as G-001. Over 600 reservations have been received by NASA for canisters of this type; 50 have been launched, plus three relaunches (or reflights), making a total of 53. Note, however, that several other varieties of GAS can have been launched as well: the West Germans have their own version, GSFC has several versions, and some canisters were adapted for special applications that are worth mentioning. The total number of "nonstandard" GAS cans launched is 24, making the total of all cans 77. (Identifying these canisters and their experiments required two months of inquiry and detective work!)

For this study, any canister with the same fundamental cylindrical volume of a standard NASA GSFC GAS can was included for analysis, even though such canisters are nonstandard and thus not "official" GAS cans. All cans were included because most of the integration problems encountered with standard GAS cans are encountered with the nonstandard cans as well.

To enhance the visibility of canister variety, a nomenclature was utilized that identifies the canister by type. For this paper, a detailed discussion of each type is not required; the table below is included, however, to summarize the number distribution of each type.

GAS CODE	GAS TYPE	STANDARD GSFC GAS	NONSTANDARD GAS
G-NNN	Standard GSFC GAS	50	
G-NNNR	Standard GSFC GAS Reflight	3	
DG-NNN	West German GAS (MAUS)		17
G-AAA	Special GSFC Test GAS		2
HHG-N	GSFC Hitchhiker GAS		2
G-XXX	Unassigned GAS (Postal Covers)		8
NAVEX-N	West German NAVEX Pallet GAS		3
C-360	Cinema 360, Inc. camera carrier		2
	TOTALS	53 +	34 = 77

Notes: 1) NNN = a number
2) AAA = an acronym
3) The first five types above employ NASA nomenclature; the last three are the author's own convention.

The 8 postal cover canisters were used to carry First Day Covers for the U.S. Postal Service's 25th Anniversary. Since this application did little to advance the body of scientific and technical knowledge, these cans were disregarded during the study. Thus, 69 canisters formed the basis of the analysis.

Some of the more interesting and meaningful facts about these canisters are summarized below.

- 10 of 25 Shuttle missions (40%) had no GAS cans onboard. Of the 15 missions with cans, the number of cans per mission ranged from 1 to 15, with an average of 5.13 and a median of 3.

- 58 cans (84%) had a volume of 5 ft^3; 11 (16%) were 2.5 ft^3. (One user requested and paid for 2.5 ft^3, but due to availability constraints, a 5 ft^3 can was used.) Thus, 5 of every 6 cans were the larger volume.

- 47 cans were sponsored by U.S. organizations, followed by 16 from West Germany, 4 from Japan, and 2 from Canada. Thus, nearly 1/3 of the cans were foreign-sponsored, and 3/4 of those were from West Germany.

- For all 69 cans, the distribution of primary developing and/or sponsoring organizations was:

DEVELOPER OR SPONSOR	U.S. CANS	U.S. %	FOREIGN CANS	FOREIGN %
NASA GSFC	13	19%	N/A	
DFVLR (W. Germany)	N/A		13	19%
Department of Defense (DoD)	3	4%	0	0%
Other Government Agency	1	1%	1	1%
Aerospace Company	1	1%	1	1%
Electronics Company	4	6%	3	4%
Non-Aero/Elec Organizations	7	10%	2	3%
University/College	13	19%	0	0%
High School/Grade School	5	7%	2	3%
TOTALS	47	67%	22	32%

Note that over 40% of all canisters were sponsored by NASA GSFC, DFVLR, and the U.S. DoD. Strong participation (26%) by U.S. schools is evident, as well as by non-aerospace/electronics organizations (13%). The lack of independent participation by aerospace companies worldwide and foreign universities is surprising.

- 2/3 of all cans (42) were installed in the front half of the orbiter cargo bay and 1/3 (28) in the aft half. The distribution between port and starboard sides of the bay was nearly equal (33 vs. 37, respectively). 4 cans operated while on a deployed spacecraft (SPAS) and were subsequently retrieved. 18 cans were mounted on a pallet (OSTA-2 and NAVEX)) or bridge structure (GAS Bridge) rather than the cargo bay sill.

- 9 cans (13%) had special modifications such as externally mounted experiments, opening lids, and externally mounted transmitter antennas. 6 cans (two sets of 3) were connected together electrically with harnesses.

THE GAS EXPERIMENTS

For this study, GAS experiments were defined primarily by the experimenters, either in written form (published papers, articles, etc.) or verbally over the phone. Facts about these include:

- In the 69 cans, 141 experiments were identified. 48 cans (70%) had only one experiment; one can had 13. 90% of the cans had between 1 and 4 experiments in them. The average number of experiments per can was 2.06, and the median was 1.

- 123 of the 141 experiments could be classified into one of the categories listed below; 18 of the 141 experiments fit equally well into two categories. So, a total of 159 experiment objectives (123 + 18 + 18) were addressed. The distribution of experiment objectives vs. category was:

	U.S.		FOREIGN		ALL	
EXPERIMENT CATEGORY	EXPT	%	EXPT	%	EXPT	%
Materials and Fluids	44	37%	25	64%	69	43%
Technology Demonstration	26	22%	6	15%	32	20%
Biological Studies	23	19%	3	8%	26	16%
Environmental Measurements	18	15%	2	5%	20	13%
Art Projects	6	5%	0	0%	6	4%
Satellite Deployments	3	3%	0	0%	3	2%
Miscellaneous Science Support	0	0%	3	8%	3	2%
TOTALS	120	101%	39	100%	159	100%

Foreign users (mostly West Germany) have concentrated most efforts in the materials processing and technology demonstration categories, whereas U.S. users have in addition expanded significantly into biological and environmental studies.

GAS EXPERIMENT RESULTS

At the time of writing this paper, results from 11 GAS cans (17 experiments) had not been obtained. These cans were all foreign: DG-301, DG-301R, DG-302, DG-303, DG-303R, DG-315, NAVEX 1, NAVEX 2, and NAVEX 3 from West Germany (DFVLR), and G-032 and G-035 from Japan (Asahi National Broadcasting Company/NEC). So, the results presented herein do not consider these experiments. However, 84% of the cans and 88% of the experiments were considered, which is still a representative sample of the total. Thus, the initial input for the results analysis was 58 GAS canisters containing 124 individual experiments and 142 objectives.

To simplify matters, overall canister performance was assessed first in those cases where all experiments inside the canister had similar results.. Three cans were loaded with passive experiments (4 total), so little can be said about these, since active experiments were the focus of study. Next, it turns out that 22 canisters apparently operated without anomalies. And it is worth noting that all of these canisters were single-experiment cans! At the other extreme, 8 cans suffered turnon failures which precluded any chance of acquiring data from their 31 experiments. After these three cuts were made, 25 canisters were left to analyze. These cans contained 67 experiments.

At this point, individual experiments had to be studied, since all remaining cans contained a mix of experiment results. Using an appraoch similar to that used for the canisters, it was found that 3 experiments were passive and 14 operated smoothly without anomalies, leaving 50 experiments that suffered some degree of failure.

Of the final 50 experiments, 28 had severe failures and thus produced no data, whereas 13 failed moderately and provided some data, but did not adequately meet the experiment objectives. The remaining 9 experiments provided enough quality data to meet the objectives, but still experienced anomalies that are worth mentioning.

This analysis reveals that 94% of the 124 experiments studied were active, the rest passive. Considering the systems-level performance of the 117 active experiments, the following record can be stated:

Completely successful; no anomalies:	36	31%
Successful, with anomalies:	9	8%
Partially successful; some data:	13	11%
Unsuccessful; no data:	59	50%

So, the bottom line is that roughly 40% of the active experiments met their objectives, and the other 60% resulted in little or no data.

GENERALIZATIONS AND CORRELATIONS

On the overall canister performance level, it was noted above that all of the canisters that operated without anomalies (22) had only a single experiment in them. All but one of those that suffered turnon failures (8) had two or more experiments. Also, the causes for the turnon failures were all different! A similar spectrum of surprises was experienced by the individual experiments that failed (severely or moderately; 41 total) or had anomalies, even though they worked (9).

All failures studied were categorized according to the following applicable "subsystems":

Experiment Control:	Turnon/off, relays/latches, actuators, data storage
Mechanical Design:	Mounting structures, boxes, seals, joints
Power Supply:	Batteries, fuses, harness
Thermal Design:	Passive thermal control, heaters, thermal blankets
Atmospherics:	Vacuum systems, purges, pressurized systems, venting
Science Design:	Experiment concept and execution, timeline, scaling

Correlating the degree of failure with the failed subsystem generated the following data:

FAILED SUBSYSTEM	SUCCESSFUL (w/anomalies)	PARTIALLY SUCCESSFUL (some data)	UNSUCCESSFUL (no data)	ALL CASES	
Experiment Control	4	2	6	12	24%
Mechanical Design	2	3	2	7	14%
Power Supply	0	0	6	6	12%
Thermal Design	1	5	11	17	34%
Atmospherics	0	2	3	5	10%
Science Design	2	1	0	3	6%
TOTALS	9	13	28	50	100%

Experiment control and thermal problems dominated the failure history for GAS experiments (58%), followed evenly by mechanical, power supply, and atmospherics problems (36%). The following list is a nutshell summary of nearly all failures encountered.

EXPERIMENT CONTROL

- Blown fuses at turnon (wrong size fuse installed at launch site)
- Ground loop problems
- No turnon due to dead batteries
- No turnon due to stuck relays
- Wrong switch setting during final integration
- Incomplete actuator movement (jamming, loss of power)
- Turnon at KSC; a Delta launch activated an acoustic switch (!)
- No turnon due to miswired NASA/GAS interface connector
- No turnon for an undetermined reason
- Connector pulled loose by launch vibrations
- Failure of tape recorders (jamming, wrong track, controller)
- Failed cameras (jamming during launch, controller)
- Film fogging due to long wait at launch site
- Bad data storage due to low battery voltage

MECHANICAL DESIGN

- Failure of battery mechanical supports due to launch vibrations
- Cracked boxes due to freezing water expansion
- Cracked boxes due to launch vibrations leading to fluid leaks
- Dried out O-ring seals due to long waits at the launch site
- Leaking seals, leading to pressure changes and fluid leaks
- Damaged hardware during shipment to launch site
- Broken glass tube due to shipping or launch vibrations
- Membrane broken during shipment, leading to premature application of fixative to living organisms
- Canister lid failed to close due to a design flaw

POWER SUPPLY

- Dead or weak batteries due to inadequate screening and preparation
- Dead or weak batteries due to long wait at launch site
- Dead or weak batteries due to exposure to cold and vacuum in space
- Dead or weak batteries due to exposure to cold winter at launch site
- Dead batteries due to relay flip before launch
- Undersized battery packs, leading to premature turnoff
- Leaking batteries, leading to fluid contamination all over experiment
- Undetected short of power diodes during integration at launch site
- Diode fracture during launch vibration
- Intermittent shorts and relays (lights, cameras, devices)
- Sneak circuit paths, leading to excess battery drain

THERMAL DESIGN

- Frozen fluids, leading to all kinds of problems
- Severely inhibited organic growth due to low temperatures
- Stuck linear actuators and syringes due to low temperatures
- Blown fuses due to syringe actuation against frozen fluids
- Undersized heaters, leading to low temperatures and inadequate melting
- Low temperatures due to lack of thermal convection in microgravity
- Low temperatures due to heater failure or dead batteries

THERMAL DESIGN (Continued)

- High temperatures while on ground, leading to fogged film
- High temperatures due to shadowing in bay by another payload, which inhibited heat rejection to space; led to premature turnoff
- Circuit failure due to low temperatures
- High or low temperatures due to poor design of thermal control system
- Low temperatures due to off-nominal orbiter attitude history

ATMOSPHERICS

- Dead organisms due to dehydration from GAS can purge (dry air)
- Arcing vacuum tubes due to helium purge gas infiltration
- Fluids evaporated during long wait at launch site
- Arcing in vacuum during sputtering process; inadequate outgassing
- Stuck syringes due to long wait at launch site; dried out seal

SCIENCE DESIGN

- Fluids failed to mix due to surface tension
- Late turnon or early turnoff due to other mission problems
- Substandard purity of processed samples
- Incomplete dissolving of solids in liquids
- Unexpected gas bubbles in solids and liquids
- Higher than expected g-levels due to crew motion in cabin
- Launched without required fluid due to last-minute leak at KSC
- Not launched because experiment integration was not done in time!

It was mentioned previously that the 124 experiments studied had 142 objectives, since some experiments fit into two categories. (Most of the dual-objective experiments were materials processing technology demonstrations combined with a materials or fluids experiment.) Active experiments account for 134 objectives, or 94%. It is instructive to compare the success/failure results within these experiment categories, as shown below. (Here, success means the objectives were achieved; failure means the objectives were not achieved or partially achieved.)

EXPERIMENT CATEGORY	SUCCESS	FAILURE
Materials and Fluids	20	35
Technology Demonstration	16	15
Biological Studies	0	21
Environmental Measurements	12	7
Art Projects	4	1
Satellite Deployments	2	1
Miscellaneous Science Support	---No Data---	
TOTALS	54	80

Especially notable here is the high proportion of failures (some caused by GAS can turnon failures) in the biological and materials processing categories. Active biological studies have had zero success!

Some correlation between experiment success and developer group was found. NASA GSFC and U.S. non-aerospace companies had a good record of success (28 of 34; 82%), whereas U.S. schools had a dismal string of failures (54 of 63; 86%). The number of foreign experiments was too small to readily see a pattern in the data.

c-2

THE FUTURE ...

If the historical rate of GAS launches is maintained once the Shuttle activity resumes, we can expect to see another 250 to 500 GAS canisters launched before the end of the century. These cans would contain 500 to 1000 experiments of all types. New GAS features will evolve to meet user demands: longer cans, wider cans, expanded power supplies, and a host of innovative interfaces. Satellite ejections will likely be commonplace in a few years.

Besides the normal hardware and parts problems, this study has illuminated several areas of experiment design and testing that have been causing problems for GAS experimenters to date, namely:

- Operating temperatures in orbit have been frequently overestimated, resulting in frozen liquids, poor electrical and mechanical performance, underperforming heaters, and slow chemical reaction rates. Hot temperatures are also common.
- The long prelaunch wait (up to 2-3 months) precipitates battery drain problems, O-ring and seal dryout, biological organism stress, and thermal concerns, especially during winter.
- Several failures have been caused by improper experiment configuring during final integration. More extensive prelaunch functional tests might alleviate many such problems.
- Launch vibration has caused several mechanical and electrical failures involving experiment cases, relays, and wire harnesses.
- The prelaunch purge has stressed or killed biological organisms and has migrated into experiment vacuum chambers.
- Multiple experiment integration invites problems of all types.

ACKNOWLEDGEMENTS

The author wishes to pay gratitude to Mariann Albjerg at NASA JSC for helping to sort out the GAS manifest history, and for providing some valuable experiment descriptions and references. Thanks is also due to Larry Thomas, Mark Goans, Dan Butler, Lee Shiflett, and Jack Triolo at NASA GSFC for providing several inputs with regard to experiment results and investigator contacts. The assistance and tolerance of the CASS staff at Utah State University is appreciated as well. Most of all, the individual GAS experiment investigators (see reference listing) cannot be thanked enough for their experiment descriptions, summaries of results, prompt action, and frank, thoughtful discussions about their experiments, the GAS program, and their experiences with it.

The author assumes responsibility for any inaccuracies or misrepresentations with respect to the experiment descriptions, classifications, and results. Given the proper inputs and enough time, such errors should gradually get corrected.

REFERENCES

An extensive reference listing of sources consulted during this study is available from the author. Is was not printed here so that most of the eight pages could be used for presenting the study results.

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GET AWAY SPECIAL EXPERIMENTERS SYMPOSIUM
OCTOBER 7-8, 1986
GODDARD SPACE FLIGHT CENTER
PROJECT EXPLORER, GAS # 007
MARSHALL AMATEUR RADIO CLUB EXPERIMENT (MARCE)

STS-61C, COLUMBIA FLIGHT
FINAL REPORT

by
EDWARD F. STLUKA, W4QAU
MARCE PRINCIPAL INVESTIGATOR

ABSTRACT

This paper reviews the performance of the MARCE. The responses, from the World Wide Amateur Radio Ground Stations, who received the Columbia to Earth direct radio downlinks, are discussed. Likewise, the MARCE radio relay link from Columbia through the AMSAT OSCAR AO-10 satellite to Earth is reviewed.

INTRODUCTION

GAS #007 was sponsored by Mr. Edward O. Buckbee, the Director of the Alabama Space and Rocket Center, Huntsville, AL, in cooperation with the Alabama Section of the American Institute of Aeronautics and Astronautics. Dr. Konrad Dannenberg, Project Explorer Manager, performed a cohesive and superb management task of keeping the Project Explorer team together and interfacing with the Get Away Special Officials at the Goddard Space Flight Center. Project Explorer was planned to allow high school science students to fly their own experiments on the Space Shuttle.

The University of Alabama (UA) Huntsville, UA Tuscaloosa, Auburn University and The Alabana A & M University counselors selected the student proposals, in 1978.

Three student experimenters maintained their interest and persevered. They finally witnessed their experiments: Solidification of Alloys; Plant Physiology; and Crystal Growth complete the long sought flight.

The Marshall Space Flight Center Amateur Radio Club (MARC) was requested to integrate the payload and provide the power, control, measuring and data systems. The MARCE design, development, testing, coordination and flight history are described in the 1984 and 1985 GAS Experimenter's Symposium Proceedings.

The final success of the MARCE primary objective was dependent on volunteer radio amateur operators, around the world, who would receive the 435.033 MHz transmitted "Voice Message", from Columbia and relay the data to the MARC, in Huntsville, Alabama.

The secondary objective of relaying MARCE transmissions from Columbia through the AMSAT (Radio Amateur Satellite Corporation) OSCAR (Obriting Satellite Carrying Amateur Radio) AO-10 Satellite to Earth on 145.972 MHz was realized when Joel Chalmers, KG6DX in Guam, recorded a readable voice message. This amateur radio experiment objective was considered remotely improbable by the experts because of the low 5 watt transmitter power and related link parameters.

MARCE could not have been successfully completed without the positive and excellent support from those willing to provide hardware, namely: 1. Motorola, Fort Lauderdale, FL - 5 watt FM transmitter and GSE receiver; 2. National Semiconductor Corp., Interep Associates, Huntsville, AL - two sets of data system modules; 3. Zero Corp., Monson, Mass - Electronic Support Assembly Enclosure; 4. Midwest Components Inc., Muskegon, MI - Thermal Sensitive Switches; 5. ICOM America Inc., Bellevue, WA - IC-271A and IC-471A, OSCAR Ground Station Transceivers; 6. KLM & Mirage, Gilroy, CA - CA-2M-22C and 435-18C OSCAR Antennas; 7. Trio-Kenwood Communications, Compton, CA - TS-430S Transceiver, power supply and speaker, TL-922A Linear Amplifier; 8. University of Alabama, Huntsville Environmental Lab.- Guy Smith, as head of the Lab. and Principal Investigator of the Plant Physiology experiment, provided space for the GAS #007 fabrication, assembly and testing, for both the STS-41G and the STS-61C flights. The UAH also provided machine shop and related work. Guy performed a vital and major part of the detail assembly and fastener selection and provided standard laboratory test equipment.

MARCE was completed, over an eight year period, by volunteers and support from the electronics industry, The University of Alabama, Huntsville, amateur radio groups and surplus space hardware. The first GAS #007 flight, on STS-41G, October 1984, had a 57 degree inclination, had about four months of advanced coordination and publicity and was launched on Challenger as planned, however, power was never applied because of an operational error. STS-61C planning data was not available until about four weeks prior to the December 18, 1985 first scheduled launch date.

AMSAT's telemail and Amateur Radio International Nets plus the American Radio Relay League's (ARRL) W1AW bulletins were the primary pre-flight data desimination methods. The record six delays taxed the Orbiter mission operations and AO-10 timeline updating, especially to the remote areas. With the low 28.5 degree inclination and the many delays, the amateur radio coverage was uncertain. Without AMSAT and the ARRL's W1AW updates, the MARCE would have not been successful.

The bulk of the cassettes and transcriptions were sent to N6ARE, Jullian Macassey, Pasadena, CA., (AMSAT Vice President of Operations) per the AMSAT Report. Julian agreed to be the focal point for receiving and forwarding the MARCE data to MARC. A few cassettes were sent direct to MARC, per earlier MARC publicity.

FLIGHT CONFIGURATION

GAS #007 was mounted in the forward position #4 on the GAS Bridge, to maximize the distance from the aft bulkhead. The GAS Bridge was designed by the Teledyne Brown Engineering Co., Huntsville, AL. See Figure 1. The MARCE antenna, designed by Reggie Inman, was mounted so that the half-wave dipole rods were pointed in the X or flight direction, to reduce RF reflection on the cargo bay's aft bulkhead. Figure 2 shows the student experiment layout and Figure 3 is the MARCE side.

The experiment package weighted 170 of the alloted 200 pounds. The SRB Eagle Picher 50 amp hour battery supplied primary power. The 5 watt FM transmitter was turned on at the start of each minute, during each eight hour downlink.

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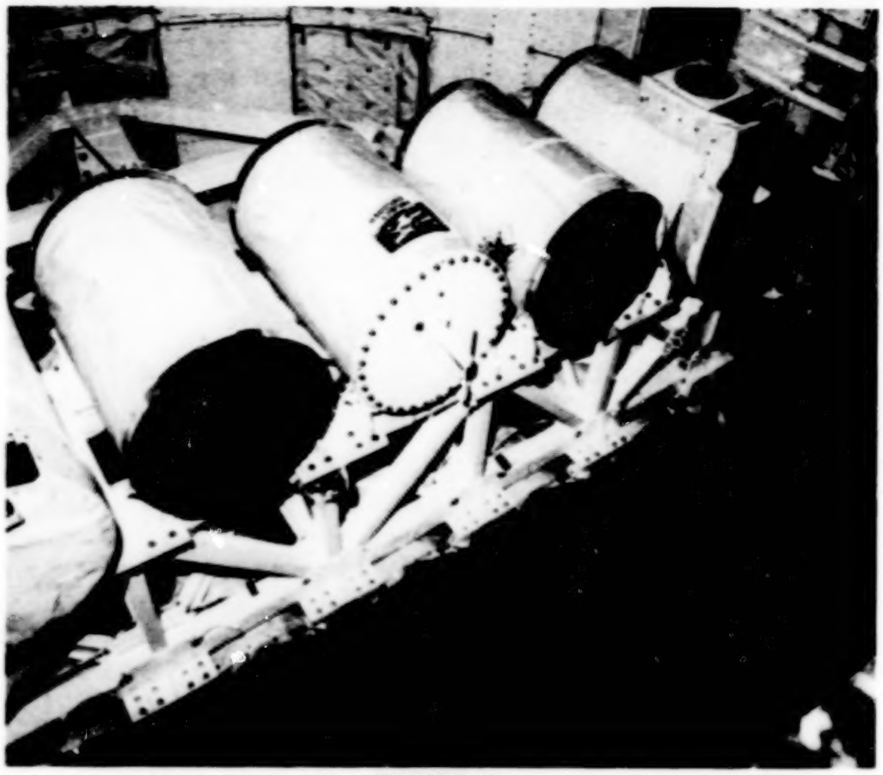

FIGURE 1

STS-61C COLUMBIA
LAUNCHED JANUARY 12, 1986
GAS # 007 PROJECT EXPLORER

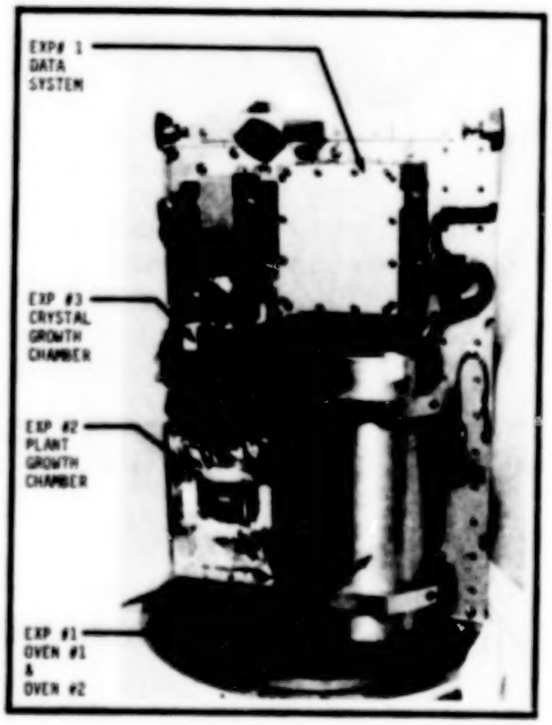

FIGURE 2

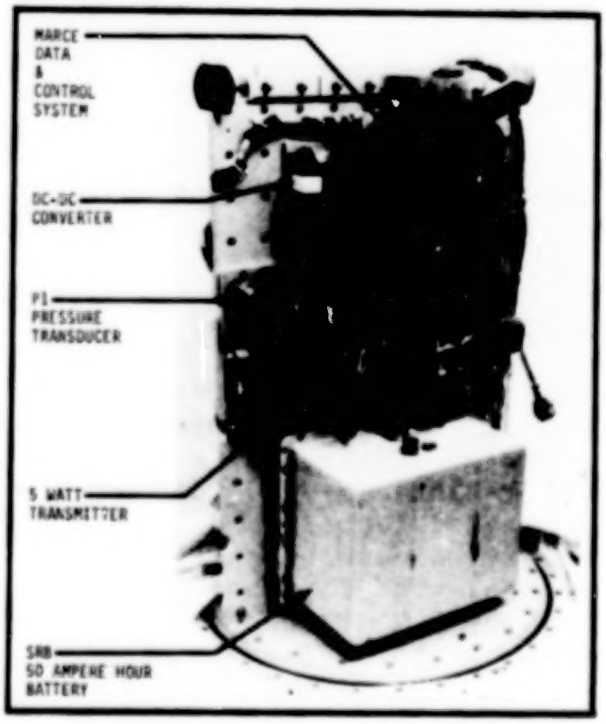

FIGURE 3

The STS-41G control system, designed by Art Davis, WB4KKA and Chris Rupp, W4HIY was configured for one transmission every 4 minutes, to conserve power. The 10 dB attenuator, required on the STS-41G mission, was not required on this mission.

The data system modules included the Digitalker™ and the NSC 800 microprocessor. The data system memory stored the voice message data every 10 minutes, through out the powered mission. The direct downlink data which was transmitted at the start of each minute, during each eight hour downlink, provided a vital set of data, that would not be available without world wide amateur radio operator support.

A total of 1,440 transmissions were programmed, for the three 8 hour downlinks. 486 messages have been received to date, which is 33.7%, of the 24 hour transmitter operation.

110 hours of GAS #007 operation were recorded in the MARCE memory, giving 660 data messages stored in memory. The one minute messages provided valuable transient data values, allowing more critical experiment performance evaluation to be conducted. The pre-prepared GAS #007 power profiles allowed a comparison of design to flight operations. The results were excellent and exciting, when the comparison was made in near real time.

PRE-FLIGHT COORDINATION

The three in-space emission notifications were sent to the FCC and approval was received. Likewise the Cape Canaveral approval for pre-flight emission tests was received. Two SRB batteries were activated and load tested. Leigh Du Pre', WB4WCX carried the GAS #007 flight package to Cape Canaveral, FL and with Guy Smith, they performed the pre-flight final assembly and tests, for the flight GAS container integration.

Gil Carman, WA5NOM, provided the STS-61C, Columbia timelines and ground tracks for downlinks 1, 2, and 3 and OSCAR AO-10 timelines, for MARCE to OSCAR AO-10 relay opportunities. AMSAT distributed this data along with AMSAT's AO-10 tracking data.

Vern (Rip) Riportella, WA2LQQ, president of AMSAT and editor of the Amateur Satellite Report (ASR), informed the world wide AMSAT community about MARCE via ASR, Telemail and the AMSAT Radio Nets.

Bernie Glassmier, W9KDR, W1AW manager, sent daily bulletins world wide, from the ARRL's powerful radio station in Newington, Conn..

FLIGHT SUMMARY AND SUPPORT ACTIVITIES

STS-61C, with Orbiter Columbia, was the 24th Space Shuttle flight. The crew: Robert L. Gibson, Cmdr.; Charles F. Bolden, Pilot; Franklin Chang-Diez, Mission Specialist (MS); Steven A Hawley, MS; George D. Nelson, MS; Robert Cenkter, Payload Specialist (PS)-RCA; Bill Nelson, PS-U.S. Congressman.

Launch occurred on January 12, 1986, at 11:55 UTC, from The Kennedy Space Center, FL. The flight completed 6 days, 2 hours and 4 minutes, with the landing at Edwards AFB, CA, on January 18, 1986, at 12:59 UTC. The launch was delayed six times and the landing attempt waved off three times.

On January 12, 1986, the MARC conducted an STS-61C and MARCE commemorative and was manned to receive radio relays of the first downlink. The first transmission started east of Ascension Island, at the end of orbit #8, at 2345 GMT. Jim Martin, K5QNI, GSFC, coordinated the NASA Ground Station amateur radio operations with Ascension and Guam Islands.

The first report received was from Gil Carman, WA5NOM, Houston, TX. Gil heard the MARCE relay through AO-10, about 30 minutes after GAS #007 turn-on. The signal was too weak to read the voice message, but the frequency, the 30 second transmissions, the spin modulation and the doppler were sufficient to confirm power-on.

The second confirmation received was from V. Rip Riportella, WA2LQQ, who relayed the 00121, 00122 and 00123 hours, voice messages received by Junior De Castro, PY2BJO, in Sao Paulo, Brazil. Junior provided the first real data revealing that the battery was healthy, the 8 status conditions were proper, as were the temperatures and the pressure. Junior provided subsequent reports by telephone, whereby the data was re-recorded on our cassette.

The downlinks 1, 2 and 3 tracking timelines were used for correlating Columbia's location and MARCE transmission times. Many of the ground stations were equipped with computers. This allowed independent tracking of Columbia and AO-10, since the Keplerian elements were available for both. The missing link was the MARCE transmitter turn-on times. This was provided through AMSAT, W1AW and other amateur radio means.

The three downlinks occurred as planned. When the STS-61C mission was cut short due to weather, GAS #007 was powered down at the end of the third day, with the other GAS payloads. However, when weather forced the first of three wave-offs, a request to power-up GAS #007 was authorized for a fourth unscheduled eight hour downlink. At the end of the fourth day, GAS #007 was again powered down, for an intended landing the next morning. When weather again extended the mission, a fifth downlink was initiated. Frantic coordination was attempted to inform as many world wide amateur radio operators as possible. The fourth downlink could not have been received, but this was not known until it was learned from the MARCE post flight memory data dump that the transmitter had not been turned on. The memory data showed that GCD relay B was not actuated, for the fourth downlink but was for the fifth downlink. This was easily varifiable by studying the I1 current reading. The data provided an excellent signature of actual operation.

On April 17, 1986, a very valuable mini cassete tape was received from JA8BSK/Kohji Yokono in Hokkaido Japan. It provided the only messages received, to date, from the fifth downlink.

FLIGHT DATA

The "POST FLIGHT DATA ANALYSIS" of the on-board MARCE memory and data system is presented in a separate paper by Charles C. Rupp, W4HIY. Chris did it all! He designed the data system, selected the components, built the pc boards from masking to soldering and testing, did all of the software and debugging. And he stuck with it during these many years. That type of dedication and individual expertise is seen in the many other persons involved in this project, and traceable to the many amateur radio operators who gave their time, postage, cassette tapes, etc. to make MARCE a SUPER success.

The "DIRECT DOWNLINK GROUND STATION RESULTS" are provided in Table 1, which lists the world wide Amateur station locations and the MARCE message data gathering details, for all direct downlink messages received. A summary of the direct downlink results is provided at the end of Table 1.

The data analysis revealed large variations in temperature, with the exception of T1, mounted on the outside of Experiment 1, Oven 1 and T2, mounted on the outside of Oven 2. T1 and T2 were designed to measure and react (control) if either oven developed an over temperature condition, which never occured. T3 through T6 revealed the colder than expected temperatures. The low temperatures, at the start of Downlinks 2 and 3 resulted from low power consumption after each downlink. T3 shows warmer temperatures because of Experiment 2 heater. T4 shows a colder than expected condition - Experiment 3 heater batteries expired. T5 measured the canister internal ambient temperature. T6 was located in the center of the SRB battery. V1 and I1 measured the SRB battery voltage and current. Both were nominal, even with the temperature far below the expected low of -5° C. P1, the cansister pressure, varied with the temperature, as expected. The measurements were taken directly from the data provided by those listed in Table 1.

The response from those listed in Table 1 was beyond our wildest expectations. The data is extra special, as it filled the gaps, between the 10 minute on-board data storage points, in significant numbers. The annotations on the data cassettes and letters received were very interesting and supportive of MARCE, the Space Shuttle Program, the Get Away Special Program and Amateur Radio.

The many hours of tracking, listening and planning, by the large group of ground station operators is evident by the Table 1 analysis. Those who attempted to receive the AO-10 relays spent many hours with disappointing results. The many hours of cassette recordings is factual evidence. Many AO-10 relay signals are recorded, with the spin modulation very evident, but no voice messages because of the very weak signals. The 30 and 45 second transmissions are also evident.

A special commemorative certificate will be sent to all those participating in this very successful space experimentation venture.

STUDENT EXPERIMENT RESULTS SUMMARY

Experiment 1, Solidification of Alloys, Ovens 1 and 2 performed as planned. A thermocouple in each oven malfunctioned. Redundant thermocouples gave the temperature readings needed.

Experiment 2, Plant Physiology, did not have the 120 hours desired. Less than 70 hours were available due to the shortened mission. Also, the growth chamber was colder than planned. A few centimeters of root growth did occur, so a limited success was realized.

Experiment 3, Crystal Growth, likewise had limited success. The heater batteries expired, resulting in a colder environment than planned. A few millimeters of crystals grew. These short crystals made it extremely difficult to make measurements. Also, the solution froze and thawed during the mission. The effects are being studied.

MARCE DIRECT DOWNLINK VOICE MESSAGES

CALL	NAME	PLACE	# OF VOICE MESSAGES
CE3BCF	JAIME G. COSTABAL	SANTIAGO, CHILE	6
CE3KB	RAMON C. JIMENEZ	SANTIAGO, CHILE	14
CE3XK	RENATO C. REEVES	SANTIAGO, CHILE	31
F1CDC	CLAUDE CARLIERE	L'UNION, FRANCE	5
JA2BGX	KAZUYUKI OKUMURA	SHIZUOKA, JAPAN	35
JA2GSD	KIICH YAMAGUCHI	SHIZUKA-KEN, JAPAN	30
JA2NCF	AIJI KAWAI	SHIZUOKA, JAPAN	28
JA3CF	YOSHI HIRO	WAKAYAMA, JAPAN	4
JA3XJK	TERUO KURODA	JYOUD KYOTO, JAPAN	12
JA8BSK	KOHJI YOKONO	HOKKAIDO, JAPAN	7
JA8PL	M. SATO	HOKKAIDO, JAPAN	2
JE3MXU	HIRO	JAPAN	4
JH1RNZ	ISAO NAKASHIMA, MD	KANAGAWA, JAPAN	28
JH2DCW	SHINNOSUKE YAMADA	SHIZUOKA, JAPAN	9
JH3FDA		JAPAN	17
JH6EGU/2	MICHIYASU SAKAIDA, MD	TOKIWA, JAPAN	19
JH7CKF	HAJIME JUKUDA	KWATE, JAPAN	8
JI1VYH	YASUO NAGAI	TOKYO, JAPAN	NO TIMES
JR1RBR	KEIJI IMAI	TOKYO, JAPAN	5
=====	MINORU OHMINE	OKINAWA, JAPAN	5
KG6DX	JOEL CHALMERS	LATTE HEIGHTS, GUAM, IS	70
PY2BJO	JUNIOR T. DE CASTRO	SAO PAULO, BRAZIL	47
VK5AGR	G. R. RADCLIFF	CLARENCE PEAK, SOUTH AUSTRALIA	7
WH6AMX	RICK G. DITTMER	HONOLULU, HAWAII	10
ZD8LM	LEE MC LAMB	ASCENSION, IS	44
ZL1AOX	IAN ASHLEY	AUCKLAND, NEW ZEALAND	14
ZL1PK	PHIL KING	ROTORAU, NEW ZEALAND	1
ZL1TEE	R. RALPH CARTER	AUCKLAND, NEW ZEALAND	2
ZS6AKV	J. VAN DE GROENANDALL	RYNFIELD, SOUTH AFRICA	8
ZS6BMN	JAN HATINGH	VERWOERDBURG, SOUTH AFRICA	6
5Z4EG	ANTHONY G. HIGBY	NIROBIE, KENYA	3
5Z4RG	ALAN HORNE	NIROBIE, KENYA	6

SUMMARY OF MARCE VOICE MESSAGES

	%	No.
JAPAN	44	213
ALL OTHERS	56	273
TOTAL		486

TABLE 1

SUMMARY OF GROUNDSTATIONS

	No.
JAPAN	16
SO. AFRICA	2
ASCENSION, IS	1
AUSTRALIA	1
BRAZIL	1
CHILE	3
FRANCE	1
GUAM, IS	1
HAWAII	1
KENYA	2
NEW ZEALAND	3
TOTAL	32

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USC/AIAA STUDENT GET AWAY SPECIAL PROJECT LIQUID DROPLET COLLECTOR EXPERIMENT

by

Raymond J. LeVesque, II

ABSTRACT

This experimental payload was developed in order to observe, in a micro-gravity vacuum environment, the characteristics and stability of a thin fluid film flowing across a slightly curved surface. The test apparatus was designed based upon various ground-based thin film investigations, combined with the constraints imposed by the rigors of launch and the space environment. Testing of the fluid test article at atmospheric pressure and in vacuum verified the design provisions employed concerning ultra-low inlet pressure pump construction, as well as confirming expected pressure losses in the system. During the course of hardware development and construction modifications were required; however, the overall payload configuration remained largely unchanged. This will allow for modification and reflight of the apparatus based upon the findings of the initial flight. The specific applications of this experiment include Liquid Droplet Radiator development and various forms of material transport in vacuum.

Eight years ago, the Los Angeles Section of the American Institute of Aeronautics and Astronautics (AIAA) secured the future use of a 200 lb. payload Get Away Special (GAS) container. They intended for this GAS project to provide an opportunity for "hands-on" engineering experience for students through the numerous challenges and tasks involved in a project of this magnitude.

In November 1984, a proposal was submitted to the L.A. AIAA by a group of students under the direction of Dr. E.P. Muntz at the University of Southern California (USC). The acceptance of that proposal set in motion the USC/AIAA Student Get Away Special Project, which will investigate the behavior of thin fluid film flows in the low-earth-orbit environment.

Selection of this project was brought about by several factors, including practical application in various areas, with the most immediate being in

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the field of Liquid Droplet Radiator (LDR) research. This type of heat rejection device will emit hot fluid droplets (ave. dia., 100 microns) into space, and recapture them after they have lost heat through the process of radiation (Figure 1)[1]. LDR systems are presently being studied for use on future space facilities. These radiators may employ an "auxiliary" fluid film flow on the collection surface in order to augment the capture of droplets which have either solidified, or strayed from their original trajectories, or both. The stability and characteristics of such a fluid flow will be critical LDR systems.

Consulting the ground-based studies conducted by Dr. E.P. Muntz, at USC, and the by Grumman Aerospace Corporation, this fluid mechanics investigation was defined.[2] The primary goal is to observe and evaluate the characteristics of a thin fluid film flowing across a slightly curved surface in a micro-gravity, vacuum environment. It is desired to collect data concerning the stability of this open-channel flow for varying thicknesses. For each of these flow conditions, the pressure loss across the open surface will be recorded.

In addition to the design parameters introduced by the experiment itself, other constraints had to be considered in the payload development.[3] The payload is limited in size by the container in which it will be housed onboard the shuttle. The entire payload structure must be suspended from the Experiment Mounting Plate, stipulating, to a large degree, the orientation and placement of payload elements. Furthermore, this experimental package must withstand the rigors of launch. Control of the payload presented another design obstacle since the experiment must be largely autonomous. Additionally, thorough studies must be made in order to assure that no credible possibility of failure existed which might result in a dangerous situation, either on the ground or in space.

With the above concepts in mind, a plexiglass prototype was constructed. Experimentation yielded information concerning the physical characteristics of thin film flow in gravity. There was excellent correlation with the findings of the Grumman Aerospace Corporation, upon which the prototype was based.[4] The ability to discern fluid depth changes ("waves") was realized to be an important aspect of the on-orbit data collection process.

As the prototype testing progressed, the hardware design evolved. New observations continued to indicate necessary modifications and safety concerns, as well as defining which data were pertinent. Ideas and suggestions from other GAS users furthered this design refinement. A high school group in Camden, New Jersey, and individuals at Utah State University (USU) provided insights concerning payload construction and the various payload-descriptive documents required by NASA.

Dr. Rex Megill of USU was of great assistance by supplying copies of a Payload Accommodations Requirements (PAR) report and a Safety Data Package (SDP) prepared at USU. These facilitated a better understanding of the purposes and requirements of these documents. Especially for individuals having little or no previous experience in the writing of this type of report, such reports are indispensable. The use of a word processor is also highly recommended as it speeds revisions.

The GAS program has received

special interest and attention at USU, and as a result, a microprocessor controller was built for use in USU payloads. This device, tailored to the needs of small, autonomous systems such as this, is programmable, samples and stores both analog and digital data, and can control up to eight payload components. One of these USU controllers was purchased for use in this project.

Armed with a more complete understanding of fluid flow behavior, suggestions from other GAS users, and a knowledge of the guidelines stipulated by NASA, a final configuration for the test article, Niagara, emerged. While the general design is similar to the prototype, it is more compact, functional, and spaceworthy. A cross-sectional view of Niagara is shown in Figure 2.

Following the fabrication and assembly of Niagara, extensive testing took place, in both atmospheric pressure and vacuum. While the gear pump performed satisfactorily in the atmosphere, it tended to ingest air, causing turbulent, aerated flow. Such behavior did not occur in vacuum tests, where the test article developed smooth flow. Pressure recovered by the diffuser was on the order of ten percent of the supply (emitter chamber) pressure. This corresponded to the anticipated pump inlet pressure of one centimeter of water, verifying the design of the ultra-low inlet pressure gear pump. Niagara was also tested on a shaker table, and exhibited no damage nor any natural frequencies within the range of vibrations experienced by the shuttle system.

Given that the payload data will be stored in the USU controller, transducers were selected that were compatible with its logic-level inputs. The first parameter investigated was temperature. This measurement is important because of the variation of viscosity of the working fluid, Dow Corning DC-704 diffusion pump oil, with temperature. If the experiment is initiated while below 18 degrees Celsius, frictional losses may be severe enough to prevent proper pumping. Fluid temperature will also be monitored during test article operation in order to help determine the cause of flow variations. The pump motor temperature will be checked periodically as a safety measure.

The three temperatures (fluid reservoir, Niagara, pump motor) will be measured by thermistors. These devices were chosen because of their quick response, simple operation and output. A known voltage will be applied to each and the resulting lower potential recorded in the Erasable Programmable Read-Only Memories (EPROMs) of the controller. This sampling will occur every three seconds during the payload operation.

Unlike the thermistors, which will operate prior to the opening of the reservoir, the two pressure transducers will be energized once DC-704 is flowing within Niagara. One pressure measurement is taken in the emitter stagnation chamber, and the other between the diffuser and the pump (see Figure 2).Piezoelectric pressure transducers were selected based on their sensitivity to small fluctuations and compatibility with both the working fluid and a vacuum environment. As with the thermistors, these devices output a fraction of their supply voltage.

Due to the fact that small accelerations are expected during the payload operation, a three-axis accelerometer package is included. Any perturbations above a threshold level will

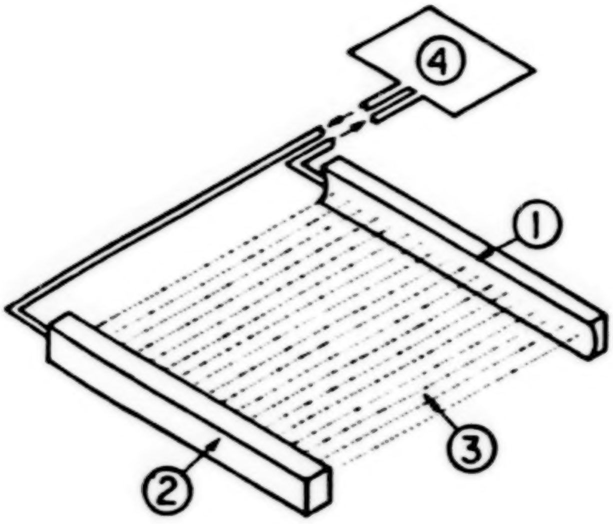


FIGURE 1

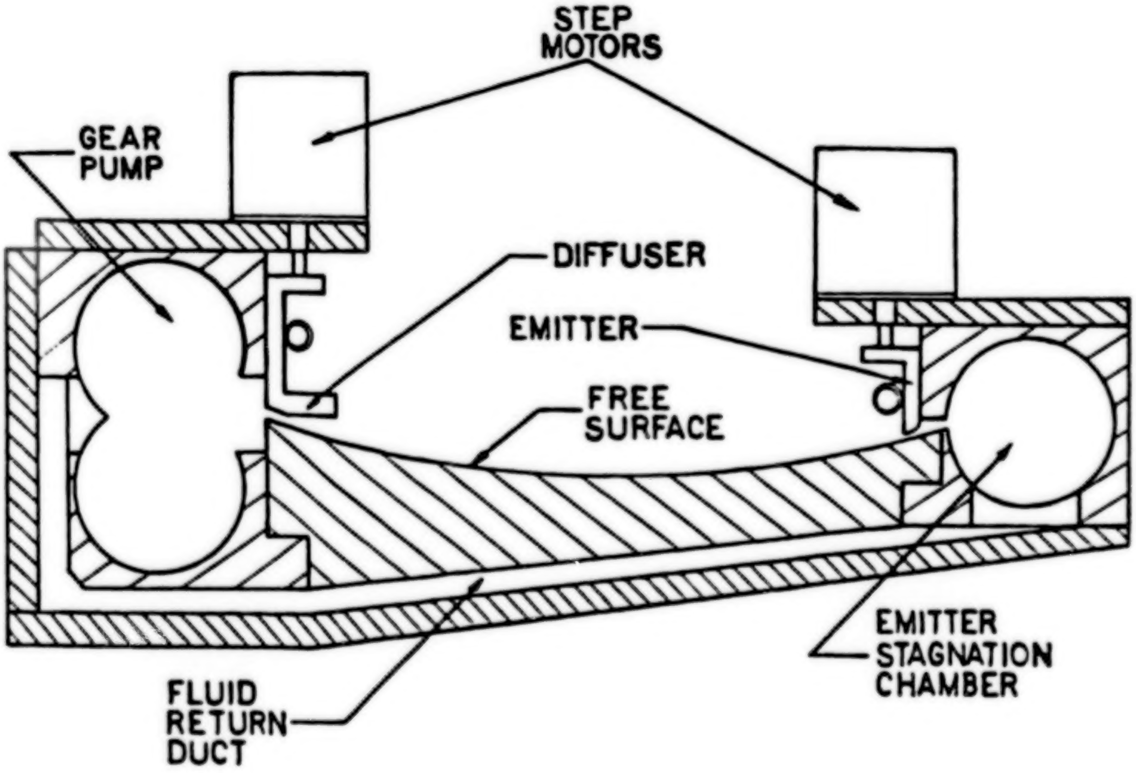


FIGURE 2

cause one or more of three LEDs to glow. This optical indication will be displayed next to the flow surface. This arrangement resulted from a belief that these accelerations will likely be random, short-lived disturbances, and as such, may not be recorded by the discrete sampling cycle of the controller. Furthermore, displaying this data in view of the camera will allow flow perturbations caused by these accelerations to be more easily identified.

The bulk of the results from this experiment will be derived from the recorded visual data. In light of this, the storage of this information received lengthy consideration, with the final decision being made in favor of a video cassette recorder (VCR) system. The most significant factor in this choice was the recording time. While a VCR offers at least 60 minutes, 8mm movie cameras provide three minutes per film cartridge. Another feature of the video camera selected is its ability to operate in low light (7 lux). Because of the length restrictions of the GAS container, the focal length, depth of field, and physical length of the camera were of interest. The camera selected has excellent macro-focus capabilities with depth of field which allows clear focus on Niagara's surface. As mentioned previously, the camera needs to be able to detect the presence of waves on the fluid surface. Analysis suggested that this would not be a problem. This theory was borne out by several tests of Niagara which were videotaped with the flight camera. Definite line were evident where waves occurred in the flow. hydraulic jump occurred in flow. Similar video systems have been successfully used on previous GAS projects, and a vibrational test of the entire payload will verify this system's qualification for flight.

Most of the payload operations, such as turning the video system on, must be accomplished by an independent, internal controller. Activation of this system will be controlled by the shuttle crew via the Autonomous Payload Controller (APC).[6] One relay connects power to the payload, and can return it to a dormant state in the event of an emergency. A second switch initiates the operation of the USU controller.

The USU controller has been connected to the various elements of the payload, and code is being developed to sequence the experimental activities. First, the fluid reservoir temperature will be sampled. Based upon this, the flow will either be initiated or delayed for a short time. When the temperature meets or exceeds 18 degrees Celsius, or when a total delay time of three hours has elapsed, the reservoir will be opened and the pump motor energized. Just prior to these operations, the video system and lights will turn on so that the start-up can be recorded. Initial emitter and diffuser heights will be maintained for the first two minutes after the flow begins. Following this, the emitter and diffuser will be raised slightly by step motors. This change in flow thickness will repeat, every two minutes, until a total of five fluid flows have been observed. After data has been recorded for each of the flow conditions, a power-down sequence will return the payload to a latent state. If the pump motor overheats, the controller will turn it off and initiate the power-down sequence.

Even more critical to the success of this experiment are the power supplies. The payload batteries are composed of 15 Gates' rechargeable lead-acid energy cells, which produce potentials of 6, 12, and 24 volts. These cells were selected for use based upon their long storage life, which is sufficient to span the period between payload delivery to NASA and on-orbit operation (typically two months). Gates' cells have been used in both military and NASA projects with favorable results, and also have performed well in past GAS experiments. A combustibility analysis of this payload verified that explosion due to hydrogen production by the batteries is not a credible failure possibility.

The safety verification documents which describe these batteries, as well as the entire payload, developed an effective basis for communication with the NASA Technical Manager (NTM). This exchange of information with the NTM, in the form of documentation and teleconferences expedited the safety procedure. This process was concurrent with the payload design, and was helpful in the development of the final payload configuration.

Several decisions which led to this final design were influenced by a concern for safety. The payload itself is split into two pieces; one-half of the GAS canister will be at one atmosphere of dry nitrogen (Figure 3), while a sealed container will be evacuated prior to launch (Figure 4).

The nitrogen environment provides the proper operating atmosphere for the electronics, in addition to effectively eliminating the potential of fire. The sealed container, housing Niagara and the fluid reservoir, simulates the vacuum of space and provides a secondary barrier against fluid escaping into the Orbiter bay. This sealed container orginally was to be vented and resealed while in orbit, but this was changed in order to eliminate Orbiter contamination hazards. The decision to mount this cylindrical chamber to the Experiment Mounting Plate (Figure 3) was driven by a desire to reduce moments induced in the mounting brackets, as well as to take better advantage of the strength of the stainless steel wall of the vessel.

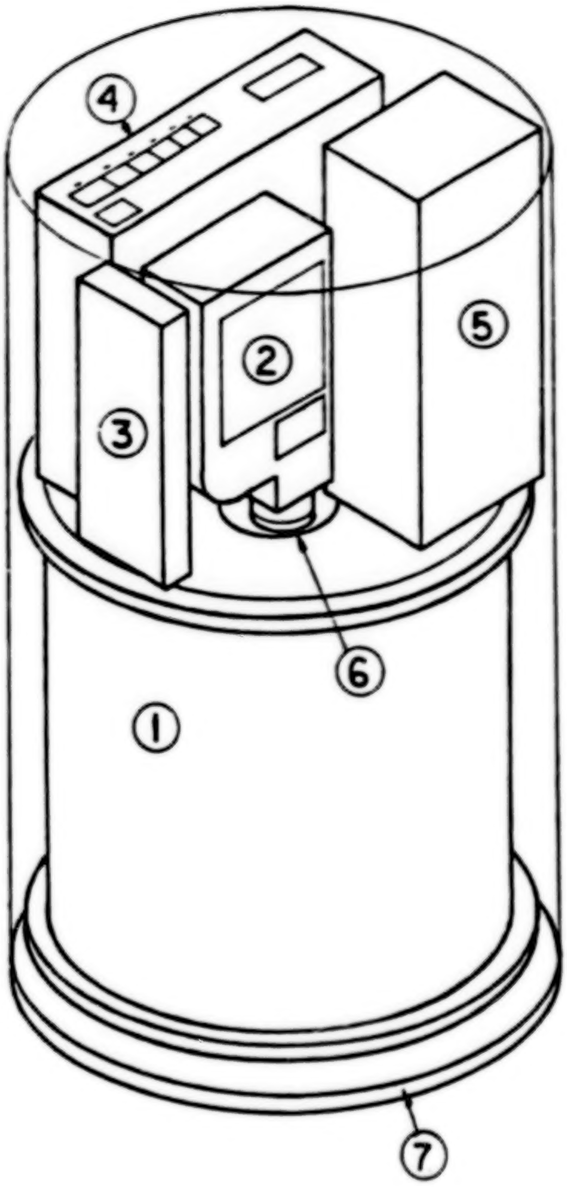
Despite these variations from the original design, the overall payload has remained functionally the same. This will not hinder the future modification and re-use of the payload. Based upon the results of the first flight, such improvements may include a droplet generator, which would allow the investigation of fluid film stability during droplet impingement (capture).

Several factors were seen to have an impact upon the evolution of the payload. Major points are summarized below:

Clear definition of the design problem prior to fabrication and acquisition of payload components is essential. The employment of the aforementioned plexiglass prototype provided invaluable insights concerning fluid flows, pump design, characteristic system pressures, and viscosity effects. Similarly, knowledge of the dimensional, material, and safety constraints imposed by NASA allowed the initial paper designs of the payload to be more realistic and appropriate than might have otherwise occurred.

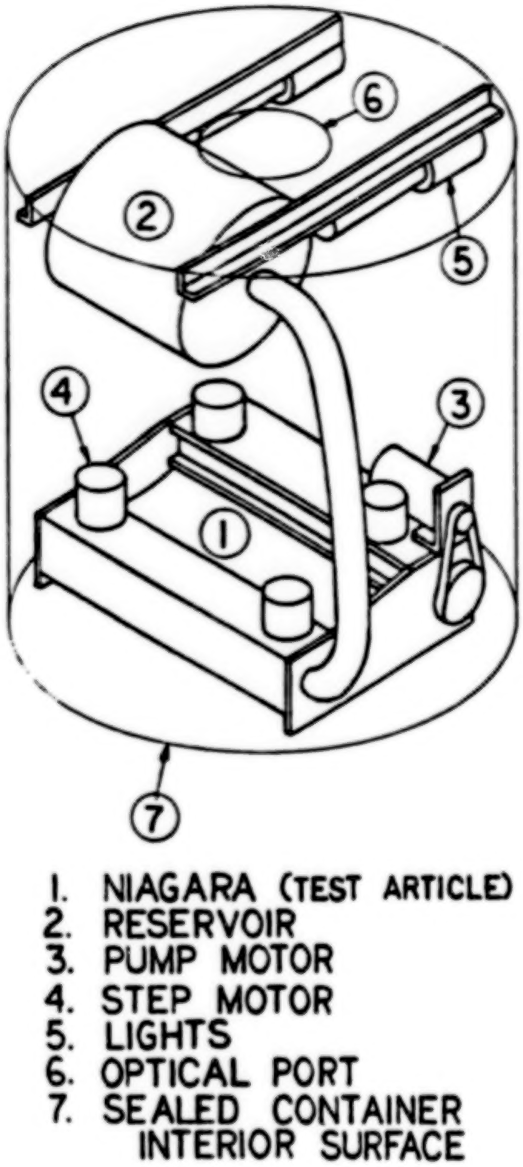
As the design progressed, it became evident that an open-minded, investigative philosophy must be maintained so that insightful discoveries were not overlooked. If the designer becomes enamored with a particular design, such as the original configuration, viable alternatives may be missed due to lack of serious consideration.

FIGURE 3



1. SEALED CONTAINER
2. VIDEO CAMERA
3. CONTROLLER
4. VIDEO RECORDER
5. BATTERIES
6. OPTICAL PORT
7. NASA MOUNTING PLATE

FIGURE 4



1. NIAGARA (TEST ARTICLE)
2. RESERVOIR
3. PUMP MOTOR
4. STEP MOTOR
5. LIGHTS
6. OPTICAL PORT
7. SEALED CONTAINER INTERIOR SURFACE

Overall system safety is an area which often requires unique approaches in addition to common sense. Here, again, consultation and research fostered a more thorough understanding of the design problem. Conferring with other GAS users who have developed and/or flown payloads yielded fresh viewpoints of the safety problems. As previously mentioned, the documentation generated during the design process served as a tool for the discovery of improvements. Inspection by qualified, objective third parties, such as NASA tehnical personnel, also proved to be very enlightening.

In conclusion, the design work, fabrication, and testing described above have resulted in the development of a compact, space-worthy payload for participation in the NASA Get Away Special program. This process was augmented by the advice and assistance of a NASA Technical Manager, other GAS users, research and experimentation, and the preparation of payload documentation. This project has also been quite successful in presenting, at the undergraduate level, an exceptional opportunity wherein theoretical knowledge was supplemented by experimentation and common sense approaches to non-trivial engineering tasks.

Acknowledgements

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RESULTS OF THE JOINT UTILIZATION OF LASER INTEGRATED EXPERIMENTS FLOWN ON PAYLOAD GAS-449 ABOARD COLUMBIA MISSION 61-C

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Payload Manager and Director of Laser Program
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ABSTRACT

The high peak power neodymium YAG laser and the HeNe laser aboard GAS-449 have demonstrated the survivability of the devices in the micro-gravity, cosmic radiation, thermal, and shock environment of space. Some pharmaceuticals and other materials flown in both the active and passive status have demonstrated reduction in volume and unusual spectroscopic changes. X-ray detectors have shown cosmic particle hits with accompanying destruction at their interaction points. Some scattering in the plates is in evidence. Some results of both active and passive experiments on board the GAS-449 payload are evaluated.

INTRODUCTION

GAS Payload G-449 (Fig. 1) was successfully flown aboard Columbia Mission 61-C between January 12, 1986 and January 18, 1986.

Payload GAS-449 operated as expected and was turned on during orbit #3, 3 hours and 43 minutes mission elapsed time and was turned off during orbit #8, at 10 hours and 48 minutes mission elapsed time. The timer on board GAS-449 operated for 30 minutes from start[1].

The payload was under development for over 2 1/2 years and combined the invited efforts of experimenters throughout the United States. The payload was flown upon the maiden flight of the GAS bridge[2]. A total of 13 GAS containers were flown upon the bridge.

The experiments were divided into four separate sections which were BMJ, LEDAJC, CROLO, and BLOTY. The BMJ experiment investigated the effects of neodymium and helium-neon laser light upon desiccated human tissue undergoing cosmic ray bombardment along with medications exposed to laser light and cosmic radiation bombardment. LEDAJO investigated radiation effects and some laser effects upon medications and medical/surgical materials and health care products. CROLO was designed to investigate cosmic radiation effects upon laser optical protective eyewear. BLOTY was designed to evaluate blood typing in zero gravity.

Six months after the mission was flown there have been some results which are now ready for publication. We expect that at year's end there will be additional material available for publication. Some of the results are as follows:

The 1 megawatt peak power miniature Q-switched YAG laser built and supplied by Laser Photonics, Orlando, Florida (Fig. 2) flown on board the payload operated as anticipated and pre-flight and post-flight testing indicates the laser to be fully operational. There appears to be no damage or side effects to the laser. The HeNe laser, supplied by Gammex Inc., Milwaukee, Wisconsin, in pre-flight and post-flight tests showed no operational damage or side effects.

EXPERIMENT REPORTS

EXPERIMENT BMJ - PRELIMINARY REPORT

Benjamin Narodick, M.D., Investigator, Cancer Chemotherapy Drug Project

The experiment BMJ was conducted to determine the effect of cosmic radiation, zero gravity and laser radiation on drugs, some of which are used in cancer therapy.

Background

A. It has been widely reported that crystal formation in space (not being subjected to gravity) results in structural arrangements different from those in gravity[3]. There are also indications that changes in the molecular structure of solid substances can also occur perhaps due to being subjected to cosmic radiation.

B. Cancer chemotherapy drugs vary in their ability to destroy cancer cells and while they have proved useful as an adjunct to surgery and X-ray radiation, mortality rate studies have been disappointing. It is possible that changes in molecular structure might enhance their effectiveness.

C. Certain drugs, such a porphyrins, are known to concentrate in tumor tissue and acting as a photosensitizer, releases singlet oxygen when exposed to laser radiation. This photo therapy effect is now limited to superficial tissue. Space changes might enhance the sensitivity of the various drugs to laser light so that deep seated cancers might be effected by photo radiation.

Procedure

The most effective cancer chemotherapeutic drugs were studied for inclusion in the experiment. All were crystalline and of sufficient potency to be placed in a small glass vials and still be sufficient for study upon return from space. The manufacturers of the drugs were contacted and approval was obtained for these companies to conduct investigations and to report any alteration that might have occurred.

Because of space limitations, the drugs were placed in three groups:

A. Nineteen vials subjected to cosmic radiation and weightlessness.

B. Eight vials subjected to cosmic radiation, weightlessness and YAG laser irradiation.

C. Three vials subjected to cosmic radiation weightlessness and HeNe laser radiation.

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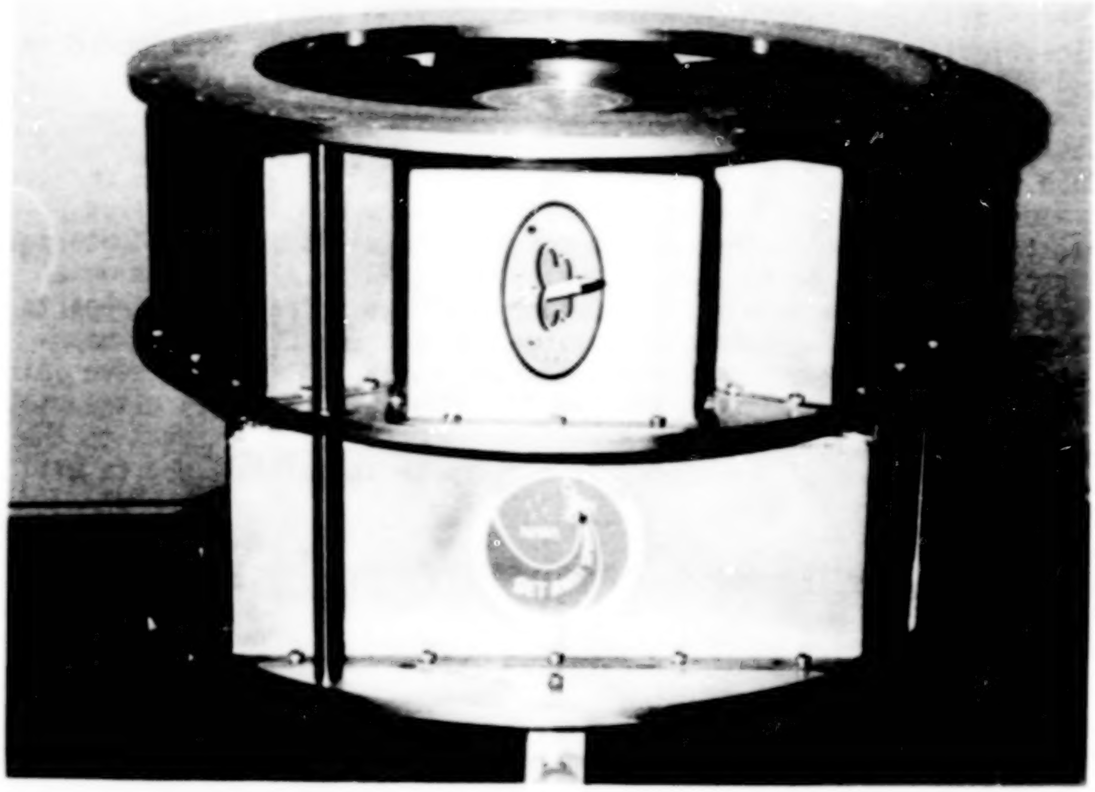

Fig. 1

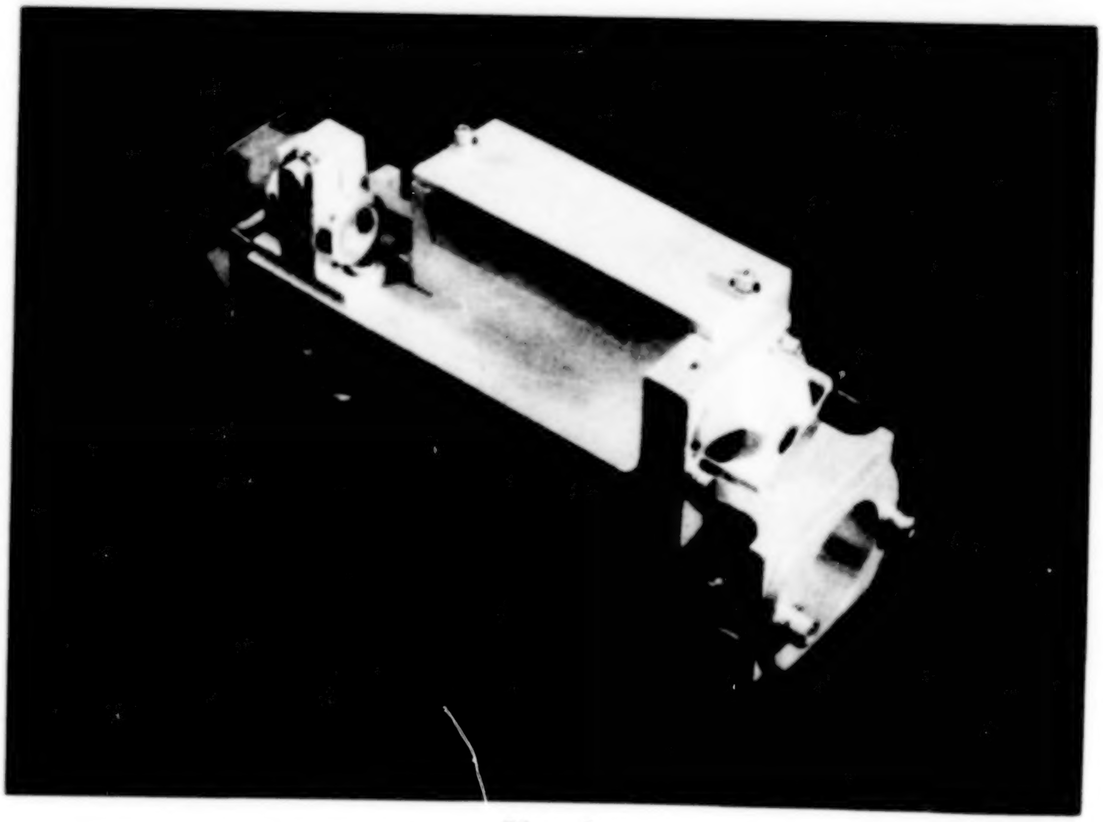

Fig. 2

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Eleven different cancer chemotherapy drugs from the four major pharmaceutical companies and nine porphyrin compounds were distributed in the three groups. Doubles account for the number discrepancy.

Results

Upon opening the BMJ experimental compartment of GAS-449, some changes were immediately apparent. Although all vials were completely filled prior to flight, it is to be noted that two containers contained clumps of material, one approximately 20% of its initial volume (Fig. 3). All samples were returned to the manufacturers for complete analysis. Preliminary reports have been requested from the pharmaceutical companies. One has already been received showing no apparent chemical changes but animal studies have yet to be completed. One investigator has suggested that some unusual ultra-violet responses have occurred and there have been other hints of changes in the effectiveness of some of the drugs. I anticipate that final reports will be available by January 1, 1987.

Laser Carbon Experiment: Erich C. Muehlenbeck, M.D., Investigator

Electron microscopy and chemical studies are ongoing - reports due December 1986.

Tissue Experiment: Joseph H. Bellina, M.D., Ph.D.

Investigation in progress. Report is expected by the end of the year.

Optical Wave Guide Experiment: Stephen N. Joffe, M.D.

Currently evaluating transmission of Nd YAG laser wavelengths through the materials in the experiment.

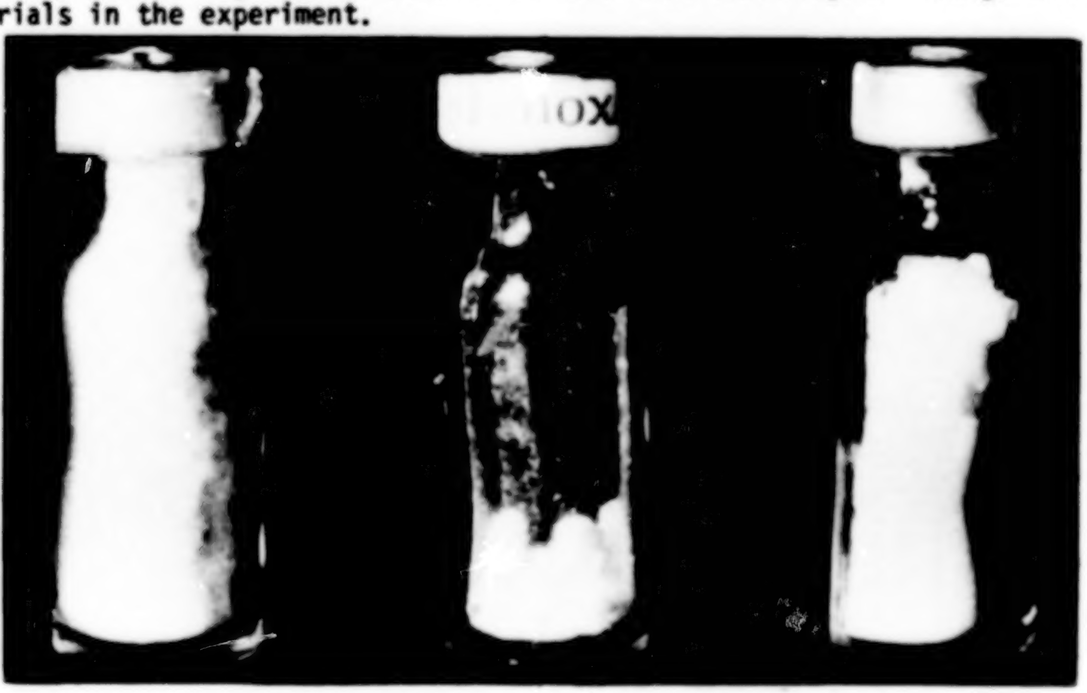

Fig. 3

EXPERIMENT LEDAJO - PRELIMINARY REPORT

Leon Goldman, M.D.

Specimens were examined grossly under sterile techniques. One-half of the specimens have been sent to manufacturers for detailed investigation. Official report by research area is expected by the end of the year.

EXPERIMENT CROLO - PRELIMINARY REPORT

R. James Rockwell, Jr.

Effects Of Space Radiations On Laser Eye Protective Filters

Following the return of the filters, spectrograpnic analysis was performed and all cases were shown to have what appeared to be the same spectrographic characteristics on all filters as prior to flight. There appeared to be some surface changes that would require electron microscope analysis. This is being pursued at this time.

General conclusion: It appears that based upon the experiences from this flight, eye projection would provide adequate protection for laser exposure had they been required to be used.

EXPERIMENT BLOTY - PRELIMINARY REPORT

R. Tom Morehead, M.D., Thomas A. Olsen, MT (ASCP) SBB, Ellet H. Drake, M.D.

Erythrocyte Agglutination In Micro-Gravity

We tested the hypothesis that antibody mediated erythrocyte agglutination would be retarded in near zero gravity by launching a self contained experiment on board the Columbia space shuttle January 12, 1986. Experiment tested Rh, ADO and Coombs sensitized human red blood cells against their appropriate anti sera and diluentes. A self contained device was built which mixed and pumped the reagents through tubing and collected the agglutinates on filter paper after optimal mixing and delay. The device was flown aboard GAS-449 in an insullated cannister which was carried on the bridge of the payload bay of the Columbia. The experiment was initiated on the third orbit about 3 hours and 43 minutes after launch. After conclusion of the experiment, the agglutinates were held on filter paper.

Both the Rh and Rh control test systems failed because of crystallization of the high protein antibody reagent. The remaining three systems functioned as expected. After comparing these results to similar experiments adopted in our lab under full gravity, we conclude that ADO and Coombs sensitized blood grouping tests do occur under micro-gravity although the agglutinates formed may be smaller and less discrete. We are exploring reasons for this difference. To our knowledge, this is the first experiment that tests blood agglutination in space.

DETECTORS

Investigation into the cosmic radiation effects upon CR-39, Lexan and X-ray plates will be part of a future paper. However, the X-ray plates (Kodak EP-21) have exposure and particle hit points. The CR-39 and Lexan are under evaluation and because of their attitude relationship to each experiment, we do not expect results before the end of the year. The materials mentioned were flown as detectors to ascertain cosmic radiation hit points and were located at discrete positions in each cannister aboard the payload.

OTHER PHENOMENON

Additionally, there are pits (Fig. 4) on the outside surface of the cannister containing the laser. The cannister is made of 303 stainless. The source of these pits is undetermined.

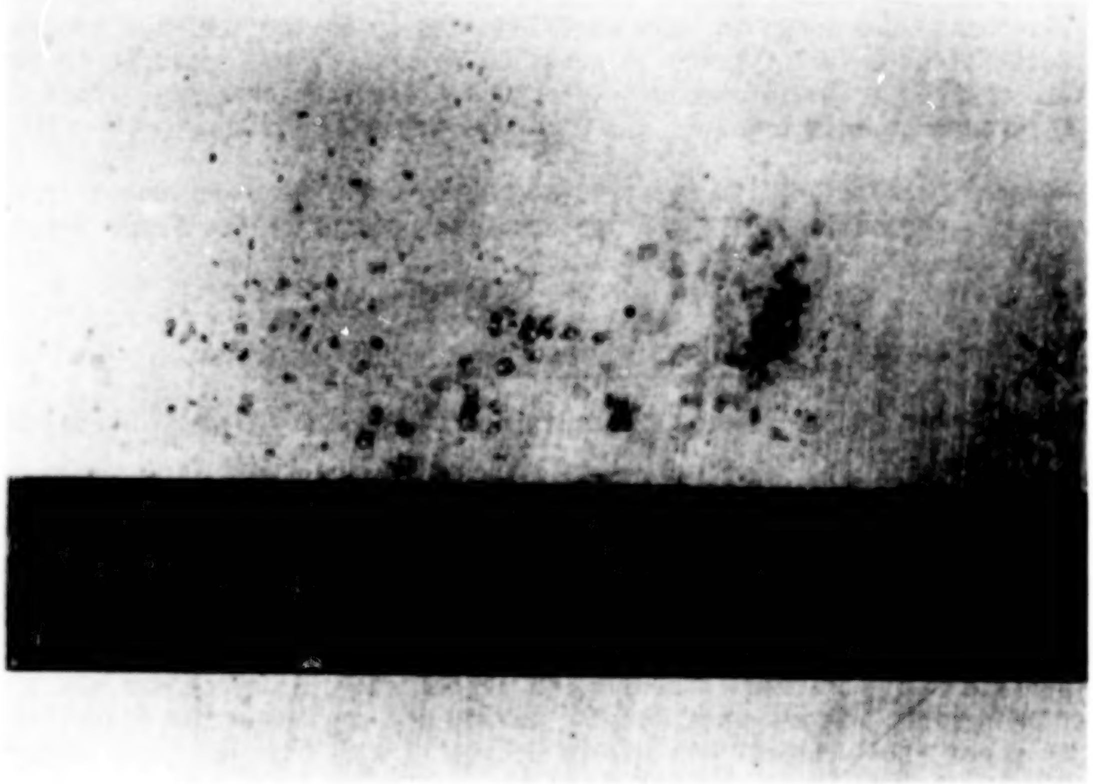

Fig. 4

CONCLUSION

The performance of GAS-449 on board the Space Shuttle Columbia Mission 61-C performed in some instances as expected and in many instances beyond our expectations, an example of which is the YAG laser. Continuing investigation into the experiments is expected to yield additional positive results. Some data may remain unexplained due to phenomenon not understood at the present. The systems which triggered the experiments functioned perfectly and the timing of the experiment was 30 minutes. There have not been reports from all of the investigators at the time of this writing. Investigation into the experiments will continue and will be the subject of a future paper.

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ACKNOWLEDGEMENT

The GAS-449 project was supported by Seton Health Care Foundation whose contribution made it possible to design and structure the payload to accommodate the experiments flown by the investigators. We also wish to acknowledge the following individuals, corporations and institutions who generously donated expertise or loaned parts and equipment:

PARTICIPANTS IN ST. MARY'S HOSPITAL NASA SPACE SHUTTLE LASER PROJECT

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SHARAM FOROOZAN, Project Engineer, Hughes Aircraft Company, Space and Communications Group, Los Angeles, California
JOHN GOLDMAN, M.D., Medical Staff, Northside, St. Joseph's, and Scottish Rite Children's Hospitals, Atlanta, Georgia
LEON GOLDMAN, M.D., Professor Emeritus of Dermatology, University of Cincinnati Medical Center, and Director, Laser Treatment Center, The Jewish Hospital, Cincinnati, Ohio
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R. JAMES ROCKWELL, JR., President, Rockwell Associates, Cincinnati, Ohio
P. DANIEL SUBERVIOLA, M.D., FRCS (C), Neurosurgeon and Chairman, Laser Committee, St. Mary's Hospital, Milwaukee, Wisconsin

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ST. MARY'S HOSPITAL, Milwaukee, Wisconsin

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CONTINUING POST-FLIGHT INVESTIGATION

We wish to acknowledge those who are continuing post-flight investigation (with no preliminary reports) at the time of this writing:

SHARAM FOROOZAN, Project Engineer, Hughes Aircraft Company, Space and Communications Group, Los Angeles, California
JOHN GOLDMAN, M.D., Medical Staff, Northside, St. Joseph's, and Scottish Rite Children's Hospitals, Atlanta, Georgia
P. DANIEL SUBERVIOLA, M.D., FRCS (C), Neurosurgeon and Chairman, Laser Committee, St. Mary's Hospital, Milwaukee, Wisconsin

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We wish to acknowledge the opportunity to have worked with those at NASA whom we consider to be the best hope this nation has to continue the American dream into the future. We consider the people of NASA the best hope the world has to improve the human condition upon this planet and into the far reaches of space.

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THE NORTH CAROLINA A&T STATE UNIVERSITY STUDENT SPACE SHUTTLE PROGRAM
A STATUS REPORT 1979 - 1986

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ABSTRACT

Inspired into being in 1979 by the late astronaut, Dr. Ronald McNair, the primary goal of this student centered program is to perform two experiments, Arthropod Development Study and Crystal Growth Study. Since 1979 , 78 different students representing 12 majors have participated in every phase of development of the payload -- from coming up with the original ideas to final fabrication and testing. Students have also been involved in many extra activites such as presenting their results at annual meetings and hosting tours of our lab for local schools. The program has received extensive outside support in the form of funds, technical assistance and donated parts. The payload, made primarily out of aluminum, consists of a central column structure, a battery box, a crystal growth box, an arthropod development box, four control circuit boxes, and a thermograph box. The battery box contains 24, Eveready 6V, Alkaline batteries. The thermograph box contains 3 Ryan TempMentors. Fabrication of the payload is essentially complete and a complete testing program has been initiated.

BACKGROUND

The goal of the A&T Student Space Shuttle Program is to perform two student experiments using a space shuttle flight sometime soon after the system again becomes operational.

In addition, we have a number of secondary goals which we feel are very important. They are: to enchance the classroom experience by putting students in a real world project; to develop in students a strong sense of professionalism about their work; to have students interface with the high technology of the space shuttle; and finally, to motivate students to dream big and then go after that dream.

The two experiments involved are entitled Crystal Growth and Arthropod Development. The objective of the Crystal Growth experiment is to determine the effect of weightlessness on the shape and number of microscopic inclusions in crystals of Rochelle Salt grown from aqueous solution. The objective of the Arthropod Development Experiment is to determine the effects of weightlessness and cosmic radiation on the mating and development of the Milkweed Bug.

Our program's roots are tied to astronaut Dr. Ronald McNair, a member of the 51-L Crew who tragically died aboard Challenger last January 28th. Dr. McNair, an alumnus of our university, was selected back in 1978 as one of the original 35 space shuttle astronauts. His selection inspired us to also get involved with the space shuttle.

In May of 1979, the University made the $500.00 deposit required for involvement in the GAS program. This marked the official beginning of the A&T Student Space Shuttle Program.

To get the program going, a campus-wide contest was initiated inviting students to develop and submit ideas for experiments. The contest ran an entire semester and prize monies totaling $2,500 were donated by two corporations - TRW and Raytheon. A total of 20 papers were received from the students and the top three were chosen as winners by a faculty review committee.

Since the contest, 78 different students, representing 12 different majors, have participated in the program in a variety of overlapping activities. Most of the activities occured in our own Student Space Shuttle Laboratory.

The first activity following the contest was to conduct an extensive literature search in order to get ourselves up to date and to confirm that the three winning ideas had merit. In addition the winning ideas were also researched in the laboratory to confirm that they were feasible within the GAS constraints. The end result of this research was that one of the winning ideas was dropped with much reluctance and the other two slightly modified, giving the two experiments which were discussed earlier.

The next major step was to model each payload component out of balsa wood. We made many trips to the local hobby store. Once we had a working balsa wood model for a given part of the payload finalized, detailed drawings of that part were made. Next it was to the shop. Whenever feasible, we had students do the shop work supervised by professional machinists.

All electrical design, building and testing has been done by the students. We also tried to use computers whenever it was feasible and made sense. Some of our drawings have been done on a CAD system. The computer has also been used extensively by us as a word processor for doing reports and preparing talks such as this one.

Our typical organization over the years has been to divide the 20 to 25 students participating each year into 5 teams, each team having a faculty advisor. These teams then meet weekly to review the previous week's work and set up objectives for the coming week. Once a month all teams meet to compare progress and mutual problems.

At the end of each school year we have held an Annual Meeting to summarize the year's accomplishments. Typically 10 to 15 students make 5 minute presentations, all view graph based and well planned and rehearsed. The audience includes other students, faculty, administrators, including the Chancellor of the University, corporate and NASA sponsors, and when his schedule permitted, our astronaut Dr. Ron McNair. Following each Annual Meeting the presentations are expanded in detail and assembled into Annual Reports.

All work and no play isn't recommended, so each year our program also sponsors a campus-wide contest involving model space shuttles. The models entered are first put on display and judged for accuracy, detail and neatness. Next the models are taken outside and flown. The best combined score for display and flight wins.

A high point in the program was a bus trip in early 1984 to Kennedy Space Center for Dr. McNairs's first flight. During the first day we toured the entire center and on the next day we witnessed the successful launch of flight 41-B.

None of the activities discussed so far would have been possible without extensive outside support. Outside support has come in three forms: financial, technical and parts.

Financial support through the years has come from two corporations and NASA-Ames. The corporations involved are Raytheon, TRW - Energy and Defense Sector, Digital Equipment, RCA, Owens-Illinois and General Electric. Private funding, which is what started the program, now totals approximately $120,000. NASA-Ames' funding which started 4 years ago is through a Joint Research Interchange and now totals approximately $200,000. Of this $320,000 total, roughly 25% has gone as stipends to the students participating in the program, 25% for release time for the program's director and other faculty who have served as faculty advisors, 25% for equipment and supplies and 25% for university overhead.

Technical support has come from several sources. Representatives from TRW and NASA-Ames have made many vists to our campus to interact with the students in the program. Additional technical support has come from AT&T Bell Laboratories through one of their engineers who is on loan to the university as a visiting professor of electrical engineering and is also serving as a faculty advisor to the program.

Finally there is the area of parts support. Three additional corporations have participated in this way: Amp; Union Carbide; and NRG-Barriers. Amp donated all of the rather expensive, mill-spec connectors which we are using. Union Carbide donated 240 Eveready Energizer, No. 528 lantern batteries to meet all of our needs for both testing and flight. NRG-Barriers donated the poyurethane insulation which we used in several parts of our payload.

PAYLOAD

The payload (Fig 1) consists of a support structure, a battery box, a crystal growth box, an arthropod development box, 4 control circuit boxes and a thermograph box.

The support structure (Fig 2) consists of two circular plates bolted to a central column. The top plate of our support structure is bolted to the top plate of the GAS cannister. Bumpers required by NASA are attached to the bottom plate to prevent the suspended support structure from hitting and damaging the inside wall of the cannister.

The battery box (Fig 3) contains 24, 6V Eveready Energizer Alkaline Batteries. Twenty of the batteries are designated as heater batteries, and are dedicated to keeping the payload warm during the entire flight. The other 4 batteries are designated control batteries and are totally dedicated to running the control electronics.

The crystal growth box (Fig 4) will be used to grow a single crystal of Rochelle Salt. While still on earth a supersaturated Rochelle Salt solution is placed in the growth chamber. A seed crystal of Rochelle Salt is placed on the end of a narrow shaft, retracted and then stored behind a rupturable diaphragm in the cover. The cover is then closed down over the growth chamber. The experiment is activated shortly after launch at around 60,000 ft.by the NASA provided baroswitch. First the solution is heated and stirred to dissolve all the granules of Rochelle Salt. Following this an automatic controlled cooling process is initiated. After two days of cooling the seed crystal is inserted into the solution which has become supersaturated in the meantime due to cooling. After two more days the growth process is automatically stopped. This is accomplished by turning off the heat, retracting the cover and the grown crystal, and absorbing the left-over solution with silica gel dessicant. The recovered space grown crystal will then be compared with earth grown control crystals.

The arthropod development box (Fig 5) will be used to yield baby Milkweed bugs. While still on earth, males and females will be put into separate compartments, males in the top one, females in the middle one. The bottom compartment is left empty and will later serve as the nursery. In addition a total diet paste is put into each of the three compartments. The compartments are covered and the box is sealed shut and covered with insulation. The heaters and lights for this experiment are also activated by the baroswitch. Approximately 1/2 hr. after achieving orbit, the door is retracted uncovering an opening between the male and female compartments and uncovering the nest between the female compartment and the nursery. Hopefuly there will then be mating and 1-2 days later the females will be laying eggs in the specially prepared nest. After 4 days the door will be closed by astronaut command, thus preventing any further egg laying in the nest. As the eggs in the nest develop and hatch out, the babies unable to crawl out through the top of the nest because of the closed door above, will crawl out through the bottom of the nest into the nursery below. The babies later recovered from the nursery will be compared to earth-born and raised, control, Milkweed bugs.

Four control circuit boxes (Fig 6) contain all the electronics to run the payload. Two boxes are dedicated to the crystal growth experiment. A third box is dedicated to the arthropod development experiment and the last box is used for overall system control and interfacing with the orbiter.

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The thermograph box (Fig 7) will contain 3 Ryan TempMentor thermographs. Each thermograph is a totally self-contained unit. Each thermograph will be activated when the payload is handed over to NASA personnel at KSC. Thereafter, until we get the payload back approximately two months later, each thermograph will measure every 20 minutes and store in its own memory for later readout, the temperature of a given payload location. The three locations which will be monitored are: the battery box, the growth chamber of the crystal growth box and the arthropod development box.

ACKNOWLEDGEMENTS

Over the years many, many individuals have contributed much time and effort to the development of this program. They are to numerous to list here. It is however, fitting to list those students and faculty who carried the program forward last year: ** Students -- Electrical Engineering: Kelvin Brooks, Jonathan Hampton, Brian Burnette, Chris Webley -- Mechanical Engineering: Nate Hines, Karen Sidbury, Jerry Lang -- Chemistry: Saundra Flowers, Toni Lamberth -- Biology: Mark Melton; ** Faculty -- Electrical Engineering: Mr. Wayne Crigler -- Chemistry: Dr. Vallie Guthrie -- Biology: Dr. Jerry Bennett. A special thanks to Mr. Crigler for his extra help in getting this talk prepared.

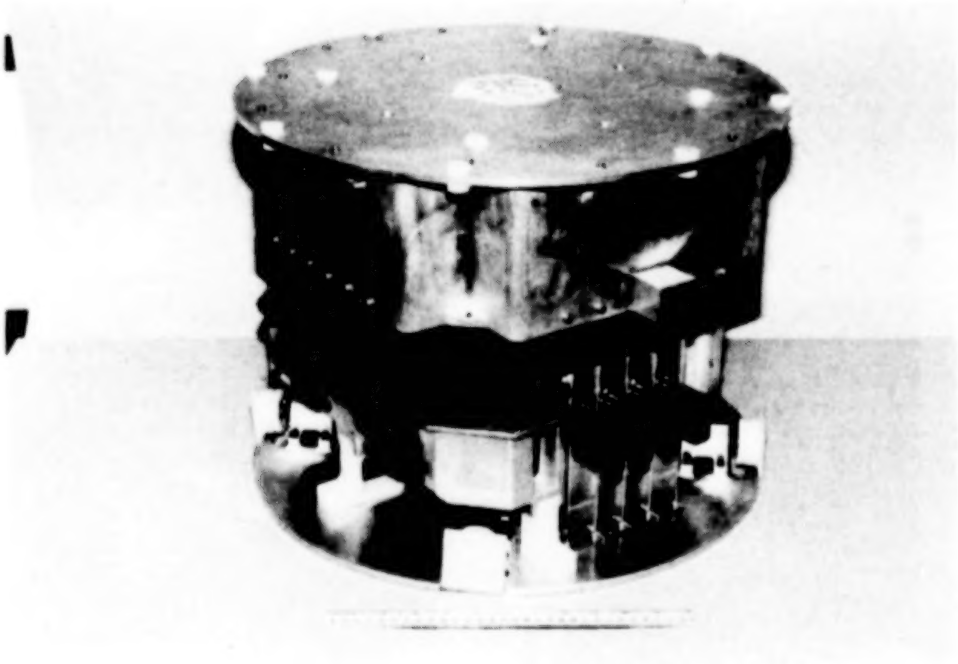

Figure 1. Payload

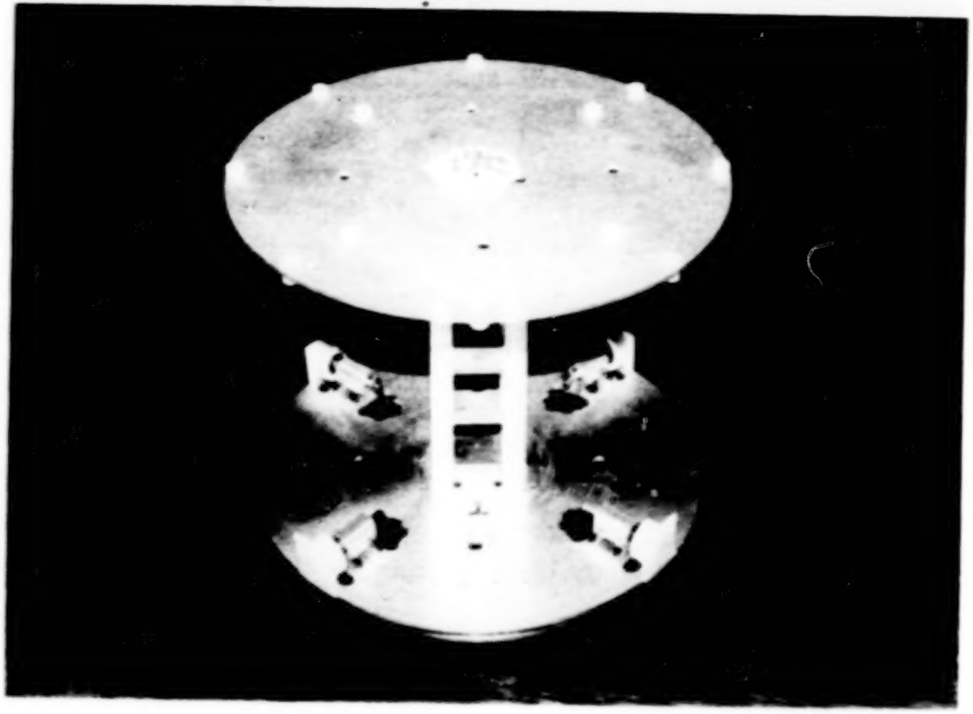

Figure 2. Support Structure

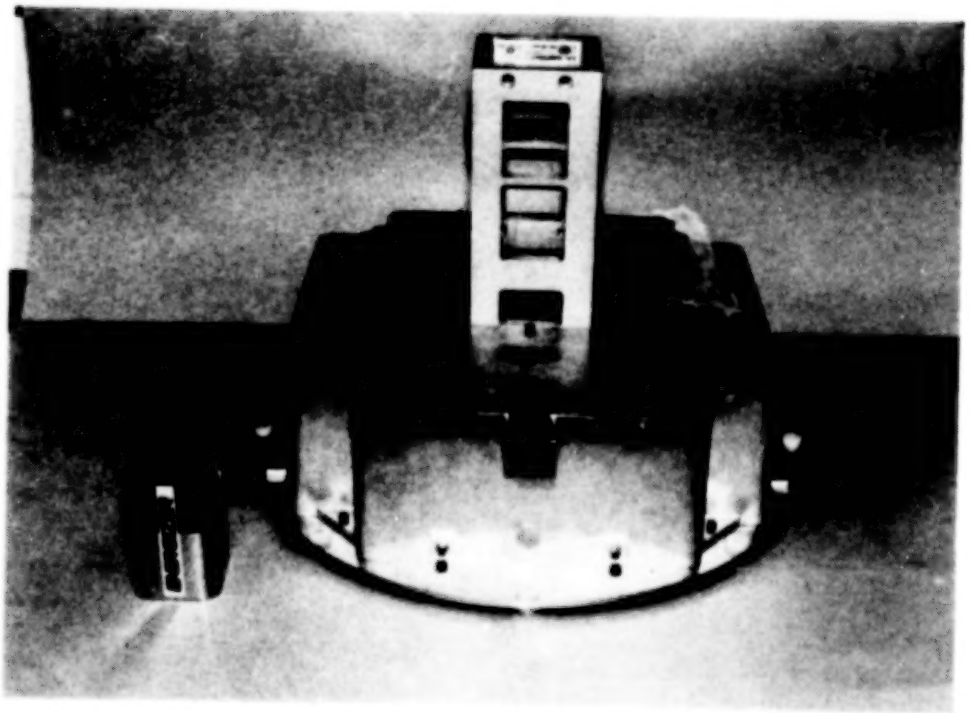

Figure 3. Battery Box

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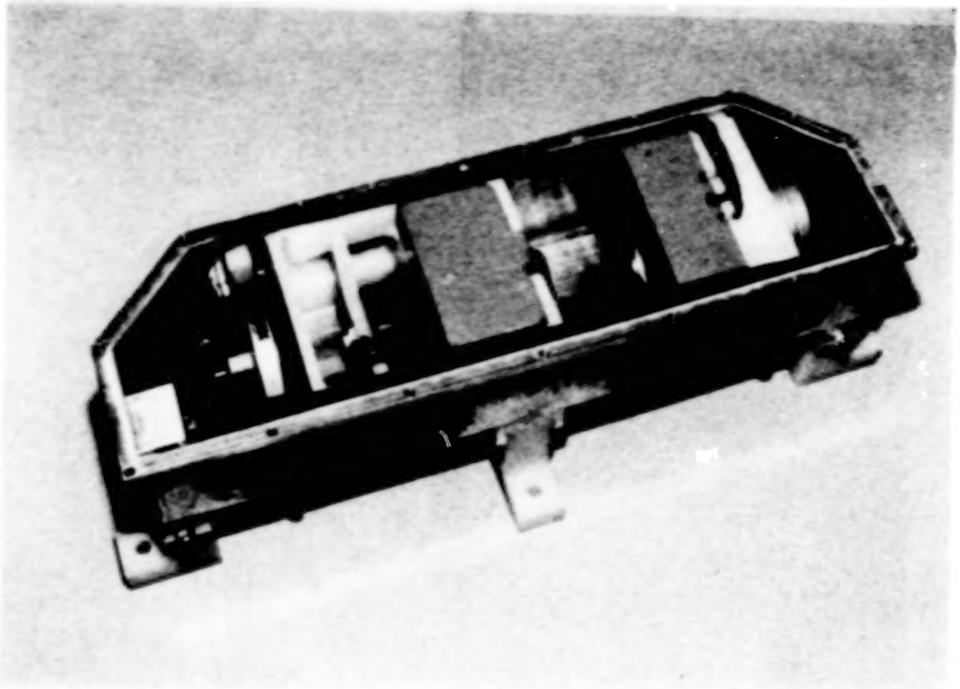

Figure 4. Crystal Growth Box

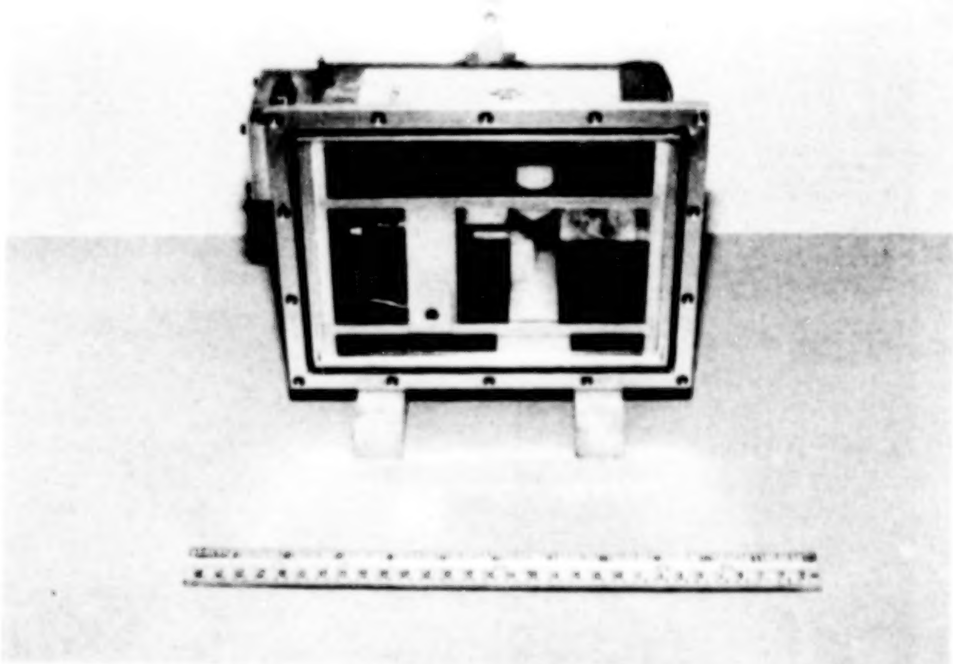

Figure 5. Arthropod Development Box

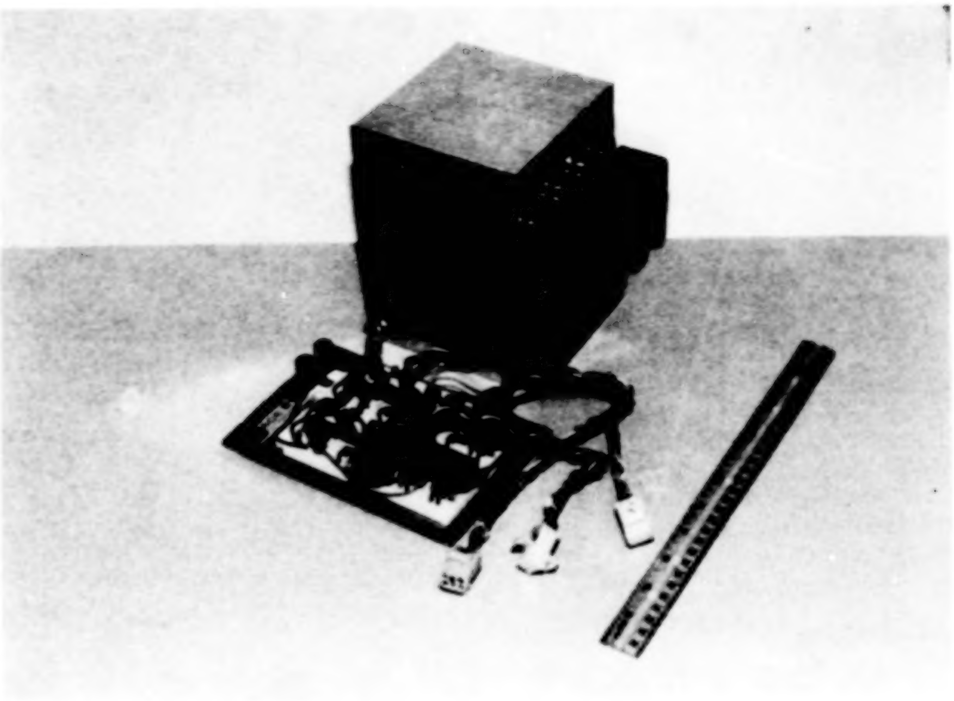

Figure 6. Control Circuit Boxes

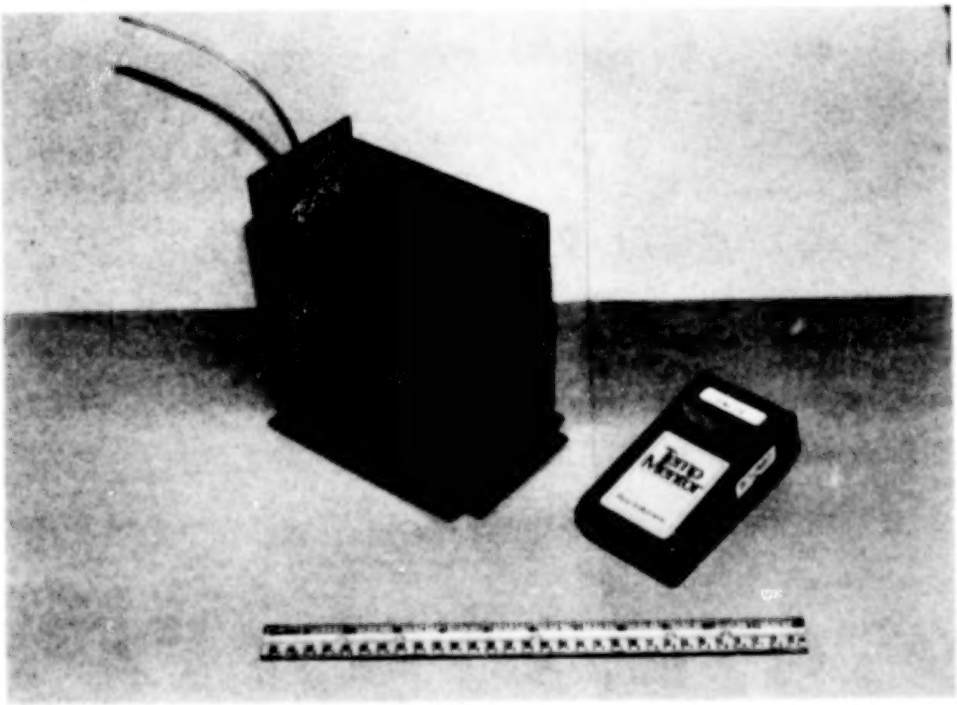

Figure 7. Thermograph Box

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BAKING THE FIRST BREAD IN SPACE

Prepared by:
Spar Aerospace Limited
Telesat Canada
Monarch Flour

ABSTRACT

The Getaway Special program is a joint venture between Spar, Monarch Flour and Telesat, with Telesat being responsible for the design, manufacture and implementation of the equipment.

The purpose of the experiment is to investigate the behavior of bread yeast in the absence of gravity and in the presence of normal atmospheric pressure. The proposed design mixes flour, water and yeast on-orbit, allows the mixture to prove and then "bakes" it.

This paper outlines the development history of the experiment, the various test programs and some of the problems encountered, with their solutions.

INTRODUCTION

In October of 1983, Spar Aerospace, Telesat Canada and the National Research Council of Canada announced a Canada in Space competition inviting all Canadians to come up with ideas for an experiment they would like to see done in space. The effort was a direct outgrowth of the Getaway Special Program.

While Telesat and the National Research Council sponsored competitions for secondary schools and universities, respectively, Spar chose to invite ordinary citizens to come up with ideas. The notion that experiments in space are not the sole domain of experts and scientists was well proven as 515 entries were submitted to Spar - 91 in the French language.

The criteria for the selection of the experiment were stringent; first and foremost it had to be feasible; it had to be capable of surviving up to eight weeks on the launch pad before liftoff; and it had to be affordable. All entries were reviewed by Spar engineers and then screened by a blue ribbon panel. Finally, in April of 1984 the winning experiment was announced; Canada was going to bake the first bread in space. There were 10 winners in all, coming from Nova Scotia, Quebec, Ontario, Alberta and British Columbia. All had voiced a common scientific curiosity in determining what effects the weightlessness of space would have on yeast.

Once the winners were chosen and properly applauded for their ingenuity at a ceremony at the Ontario Science Centre, we set about to enlist partners in the venture, experts who could assist us in bringing the experiment to fruition.

If we were going to be successful we needed help from bread baking experts. The scientific and public relations value of our experiment sparked the curiosity of Maple Leaf Mills, who make Monarch Flour, and they generously signed on as partners in our unique venture. Their task, which they are ably performing, is to assist us in choosing the proper ingredients and environment for baking bread in space. But that's easy you say...it's just flour, yeast and water. It's not as simple as you think as our expert from Monarch Flour will explain later in the presentation.

Next, we had to find someone to build our "space oven". After scouting the scientific research community and seeking advice from space hardware experts, Telesat Canada was selected to join our team. Over the last year Telesat has worked long and hard on the intricacies of building a space oven that will not only bake bread, but can be flown safely and successfully in the compact Getaway Special cannister. You'll hear their very interesting story in a moment.

Like all Getaway Special experimenters, our triumvirate is very excited about the prospect of launching our experiment. Everything has been tested and retested and the space oven is now flight ready and being stored in a cleanroom at Telesat awaiting the next shuttle flight. In it we've baked experimental earth-bound loaves of bread and we're confident that the oven will do likewise in space. Needless to say, we anxiously await word from NASA that shuttle flights have resumed. At the moment the test hardware is on display at the Food Exhibit of the Ontario Science Centre in Toronto.

Now I take great pleasure in turning the platform over to Telesat Canada who are going to explain how you build a "space oven".

BUILDING THE EXPERIMENT'S APPARATUS

Introduction

Telesat undertook the design and manufacture of the experiment, drawing experience from the implementation of its satellite and Getaway Special programs.

The primary design goals were simplicity of operation, ease of assembly and utilization of standard parts without compromising system reliability. These goals were met, in some cases by the novel use of equipment, and the build program was completed in nine months. The initial planning for the program was, by necessity, flexible because so few of the design parameters were known; however, by setting decision points and exploring multiple design solutions a schedule could be maintained. This approach required manufacturing a development model, an engineering model and a protoflight model prior to the final flight version, each incorporating refinements to optimize performance.

Using the experience gained in satellite programs the worst case of thermal conditions were defined at +40°C and -15°C, which gave adequate margins over expected conditions, a power budget was prepared (based on oven power requirements) and a weight budget was prepared. With these parameters outlined and a conceptual design the development program was planned.

Development Summary

The guiding factor throughout the development program was maintaining simplicity of design without compromising reliability.

The original concept was to provide a baking chamber containing the flour/yeast mixture, a water container and a motor driven plunger to mix the flour, yeast and water, but before embarking on a design program, there were several unknowns that required quantifying. Unfortunately, it appeared that most problems in the baking field were solved empirically, so we embarked on our own development program.

The initial problem was how to mix the flour, yeast and water to form a dough effectively and minimize the power required for the mixing. There were no published figures showing the characteristics of dough, so a series of tests were performed using various designs of beaters, which culminated in the current spiral dough hook. This design meets the requirement of effective mixing with minimal power consumption. The original design concept consisted of a plunger driven linearly, similar to a piston; however tests showed 400 kg of force were required to mix the flour and water. In addition the mix was very poor because the plunger created a hard, dry pellet at the end of its stroke and left some free water.

Agriculture Canada provided a demonstration of the "stomacher" developed to mix food for the early astronaut programs. The stomacher used two alternating paddles which provided a very good mix; however, the use of a flexible sealed container was impractical for our application. A dual plunger linear system was tried, which provided an improvement over the single plunger, but still left a hard dry pellet. The linear motion approach was discarded in favour of rotary motion using blades similar to those of a food processor. This provided a good mix if it swept the length of the chamber, i.e., combining rotary and linear motion, however it required a high torque and its performance in micro-gravity was doubtful.

The final solution was to return to the system the bread industry used, the dough hook. The original version was fabricated from a wire coat hanger and produced perfect dough in 15 seconds with minimal torque. This ensured a miniature d.c. motor could be used and, based on the available space, the baking chamber size was determined.

Having selected a dough hook design and the baking chamber size, the next stage was to characterize the motor. This was achieved by selecting a variable speed high torque motor to drive the dough hook in the baking chamber. The torque loading characteristics for various chamber fill factors were determined so the motor could be sized to provide the required torque with minimum power consumption. There were two approaches to motor selection, a custom built model to optimize performance or a compromise on efficiency by obtaining a standard catalogue model. With the desired speed/torque characteristics defined it was found that there was a negligible difference in performance between a custom built and catalogue model, so the catalogue version was chosen for reasons of availability and cost.

With the motor and baking chamber sized, the next phase was to determine the thermal characteristics of the baking chamber. Two potential methods of heating the chamber were evaluated, one using a wrap-around silicon heater, the other cartridge heaters and thermostats embedded in the chamber walls. The engineering model used a 120 V wrap-around heater powered through a variable transformer which allowed the heat input to be varied, however, temperature control was a problem. A thermostat was impractical because of available locations so a thermistor was mounted on the chamber end plate and a control circuit designed to condition the thermistor output and switch the heater on and off.

The engineering model was subjected to environmental testing under worst case conditions (-15°C) at various "dough" fill factors. The results showed that a good product could be obtained with a power input of 90 watts with almost zero soak back to the motor, which was the primary concern. In addition, the use of Fiberfrax ceramic fibre insulation ensured a long thermal decay which would continue to dry the product after active heating.

A trade-off analysis was performed on the two heater options and the embedded heaters/thermostats solution was chosen. Thermistors have guaranteed performance only up to 100°C and the required operating temperature was 150°C. The thermistor resistance at this temperature was 4 ohms so the length of wiring to the control circuit affected the temperature control making this option impractical. There were the additional advantages of weight saving (control circuit and wiring not required) and simplicity which, when taken with the reliability aspect made the choice obvious.

The next step was to find a suitable water accumulator, the initial solution of a simple syringe being rejected was unreliable. Investigation showed that most fluid accumulators were used in high pressure hydraulic systems with working pressures in excess of 500 psi and were totally inappropriate for our application. Pneumatic control systems were found to use lightweight miniature cylinders and a suitable spring loaded cylinder was selected from the standard range available. Standard 1/4 inch plumbing fittings were used to connect the water cylinder to the baking chamber and a miniature pneumatic two port solenoid valve was incorporated to control the water injection.

A complete engineering model system was assembled using a breadboard control circuit used to bake bread. Operating the system showed that the sequence of events needed changing to optimize the mix consistency; the water had to be injected after the motor was started not before. A series of tests were run to verify the sequence times and the power budget adjusted accordingly.

The power budget allocation for the water heater required verifying so a low temperature test was conducted using a water accumulator charged with water, fitted with a heating pad and insulated with Fiberfrax. The assembly was installed in a thermal chamber and stabilized at the worst or low temperature. With a heat input of 30 watts it took seven minutes for the water accumulator to reach the target temperature 70°C, which verified the power budget allocation was adequate. The power budget had caused some concern because the initial power projections required the use of silver-zinc cells; however, by optimizing the design the power requirements were reduced sufficiently to use GATES 25 AH lead acid cells and provide sufficient margin for a three month period between experiment integration and on-orbit start up.

With potential of this three month integration period there was some concern over the ability of the plumbing to remain charged with water, therefore, a leak test was performed. A water accumulator, solenoid valve and associated plumbing were charged with water under pressure and used as the leak test assembly. The assembly was checked for visible leaks and change in position over a period of ten weeks. The cylinder showed no detectable leaks over this period, so was considered suitable for this application.

It was also believed that a helium leak test might provide a quick check on the integrity of the water accumulator, so one cylinder was subjected to a helium leak test and found to allow helium to leak around the piston seals at quite a high rate. In view of this, and the success of the cylinder on a test with water, the long term test was terminated and the cylinder subjected to a helium leak test. This cylinder also leaked helium, but at a lower rate than the new cylinder.

An attempt was made to determine a direct correlation between the helium leak rate and the equivalent water leak rate, but the resulting factor suggested the cylinder would lose all the water in 42 minutes so was disregarded.

The initial test was at ambient and it was discovered that the temperature rise was slow due to excessive thermal conduction through the end plates and brackets. The design was therefore modified by changing the end plates to teflon, which effectively stopped the conductive leakage.

Testing with the new configuration was carried out with ambients of -15°C, 20°C and 40°C with no further problems. The results showed only minor differences in the temperature profiles and no noticeable difference in the final product.

Thermal tests and numerous baking trials finalized the timing and thermal requirements for the experiment, the impact being reflected by redirections in the power and weight budgets. With completion of the protoflight test program, the flight parts were purchased and the flight model assembled. The flight model was subjected to acceptance level vibration to verify the workmanship and was functioned at -15°C and +40°C to characterize performance. All tests were successful and the experiment has been sent for storage awaiting a flight.

SELECTING THE INGREDIENTS

We will introduce this portion of the presentation by describing the way bread is made traditionally and then show how the ingredients and the method had to be modified to make bread in space.

Let us first look at the main ingredients, flour and yeast. The flour used for bread in North America is made from Hard Red Spring wheat which has a high protein content, 13% to 14% and at the same time a very elastic gluten allowing it to retain gas bubbles. Gluten is the term used to describe the protein of the flour in bread making.

The type of yeast used in bakeries is so-called fresh yeast, which is a living organism which has to be refrigerated to keep it alive. Even so it only has a short life. There has been a move to Active Dry Yeast in recent years particularily in the home. This need not be refrigerated but has a life of about one year. The drawback of both these yeasts is that they have to be activated with water before mixing with the flour. Traditionally the yeast is mixed with warm water and this suspension is mixed with the flour. Small amounts of shortening, sugar and salt are also often added for texture and flavour development.

The dough then has to be mixed vigorously to start the fermentation. In a bakery, powerful mixers are used but in the home the dough has to be kneaded and rekneaded. The dough is then set aside for about one hour at 40°C to rise to double its volume. This is called proofing. Next it is "punched down" to eliminate large gas bubbles and then shaped into loaves and placed in a baking pan to again rise for about one hour. It is then baked at 175C for 30 to 45 minutes. The bread at this stage has a shelf life of only about one week. As you can see this type of process would not be practical for a Getaway Special experiment.

Fortunately there have been advances in making both flour and yeast in the past five years which have allowed us to adapt baking to fit the constraints of a Getaway Special experiment.

Ascorbic acid (vitamin C) and l-cysteine (an amino acid) can now be added to flour and these together remove the necessity for such vigorous mixing and at the same time remove the necessity for the first proofing stage. Thus the dough can be mixed and immediately shaped to fit the baking pan and then allowed to rise just once before baking.

There is also a new process for making active dry yeast which doubles its shelf life to two years when packed in nitrogen, but more importantly it does not need to be mixed with water first. Thus, it can be added to the flour in the dry stage to be activated when water is added to the flour.

If it were not for these two recent technological advances our Getaway Special experiment would not have been possible. The thought of an astronaut mixing flour, water and yeast in micro gravity conjures up a vision of a very dusty shuttle cabin.

The process we have devised to make the first bread in space is surprisingly very simple. Firstly, the flour is mixed with the yeast and sealed in the mixing chamber which is flushed with nitrogen. It now has a life of at least one year. As explained by Telesat, when the experiment is started, water is injected and the mixing started. Next the proofing stage starts and finally the baking takes place. In order to prolong the life of the bread the baking is longer than normal to remove most of the water, thus what we will end up with is a bread stick.

The success of this experiment, of course, is based on the assumption that yeast will work normally in micro gravity. Only when the experiment flies will we know whether our assumption is correct.

If everything goes as planned, who knows, we could be setting the stage for the first bread baked aboard the space station.

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HITCHHIKER-G, A NEW CARRIER SYSTEM FOR ATTACHED SHUTTLE PAYLOADS

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July, 1986

ABSTRACT:

A new carrier system has been developed for economical and quick response flight of small attached payloads on the space shuttle. Hitchhiker-G can accommodate up to 750 lb. of customer payloads in canisters or mounted to an exposed plate. The carrier connects to the orbiter's electrical systems and provides up to six customers with standard electrical services including power, real time telemetry, and commands. A "transparent" data and command system concept is employed to allow the customer to easily use his own ground support equipment and personnel to control his payload during integration and flight operations. The first Hitchhiker-G was successfully flown in January 1986 on STS 61C.

HITCHHIKER PROGRAM

The Hitchhiker Program was initiated in early 1984 by the NASA Office of Space Flight with the objectives of providing a quick reaction and low cost capability for flying small payloads that required somewhat more services than Get Away Special (GAS) experiments but did not require the extensive, custom, services of a Spacelab. The Hitchhikers are to be flyable as little as six months after being manifested and will be flown four times a year on an opportunity basis. Two versions of Hitchhiker were selected: Hitchhiker-G, developed by Goddard, can carry up to six customer payloads weighing a total of up to 750 lbs.; Hitchhiker-M, to be developed by Marshall, will carry up to three payloads for a total customer weight of up to 1170 lbs. The electrical and mechanical interfaces of the two Hitchhiker carriers are different but the program management and manifesting will be done in a similar manner.

Hitchhikers and their payloads are provided with power, command, and data services from the orbiter using a new special harness in each orbiter which allows a Hitchhiker to be flown without interfering with up to four primary payloads on the same flight. Hitchhikers are carried in "bays" 2 and 3 near the forward end of the payload bay. Hitchhiker-G is side mounted on the starboard side to avoid interference from the RMS which is normally carried on the port side. In order to meet the requirement for quick reaction Hitchhiker-G is designed with standard pre-defined electrical interfaces and also has special transparent data system features to reduce the time required to perform electrical integration and checkout of the customer hardware to the carrier. Mechanical interfaces are also simple and consist of a flat vertical plate with a 70 mm. grid hole pattern or a canister similar to GAS with or without a motorized door.

Hitchhikers are considered secondary payloads and may not interfere with primary payload requirements on the same mission. Unique crew activity and attitude (pointing) requirements of a limited nature (eg. several hours) can usually be accommodated but may extend the lead time requirement.

SHUTTLE PAYLOAD OF OPPORTUNITY CARRIER (SPOC)

The Hitchhiker-G was implemented using the Shuttle Payload of Opportunity Carrier (SPOC). In addition to Hitchhiker-G, SPOC is being used to support non-Hitchhiker programs which are manifested as primary payloads and are therefore not limited with regard to payload weight, crew activity, pointing requirements, etc. within the normal STS capability. Currently the largest of these is the Shuttle High Energy Astrophysics Laboratory -2 (SHEAL-2) which weighs over 12000 lbs. and is over 20 feet long.

The SPOC system is designed to be modular and expandable in accordance with payload requirements to allow maximum efficiency in utilizing orbiter resources and thereby increase the potential for early manifesting on the Shuttle. Various SPOC configurations starting at 500 lbs. total weight are shown in fig. 1. (Hitchhiker-G is confined to configurations occupying only two bays.)

The SPOC system consists of the following elements:

The avionics unit provides standard electrical interfaces for up to six customer payloads. It contains a microprocessor control unit, relay switching equipment, medium-rate multiplexer, and other hardware necessary to interface with the customer hardware and orbiter. A small hand controller in the cabin allows the crew to activate and de-activate the payload and provides an independent command path to control inhibits to any hazardous functions.

The SPOC plate provides a 50 by 60 inch mounting surface for the avionics and customer hardware. The plate accepts 3/8 inch bolts on 70 mm. centers and is equipped with heaters, thermostats and thermistors for maintaining and measuring thermal control of the plate and mounted hardware as well as thermal blankets and surfaces for the back and unused portions of the front of the plate. Plate mounted customer hardware may need additional customer provided blankets, heaters, or other thermal control provisions.

The SPOC motorized door canister has mechanical interfaces nearly identical to a GAS canister and can accommodate a customer payload of up to 170 lbs., 19.75 inches in diameter and 28 inches deep. A sealed canister (no door) can also be chosen and can accommodate 200 lbs. of payload in an atmosphere of nitrogen or air. The canisters are not insulated and can radiate somewhat more heat than GAS canisters. The customer's payload must contain heaters and thermostats to maintain the desired temperature.

The standard electrical interface or "port" consists of a signal cable and a separate power cable which provide the following:

o Two 28 V (+/- 4 V) 10 Amp. power lines which can be turned on (together) by ground command. Customer power and energy are monitored by the carrier system. The maximum simultaneous total customer power for a Hitchhiker is 1300 W and the nominal maximum total customer energy is 6 KWH/ day with additional energy negotiable.

o Four 28V bi-level or pulse commands (10 ma max) which can be used with relay drivers and relays to control additional power switching within a payload. (For canister payloads one command is reserved for control of the door.)

o An asynchronous 1200 baud uplink command channel.

o An asynchronous 1200 baud low-rate downlink data channel. This data is available over Ku-band service or S-band service and can also be recorded on the orbiter's tape recorder.

o A medium-rate downlink channel 1-1400 KB/s for use with the real-time-only Ku-band TDRS service. The total simultaneous customer data rate for the Hitchhiker-G cannot exceed 1400 KB/s.

o IRIG-B serial time code and a one pulse per minute square wave signal which can be complemented by a time command via the above asynchronous uplink channel.

o Three channels for temperature sensors to allow measurement of payload temperatures even when the payload power is off (for canister payloads these channels are reserved for door position, canister pressure, and temperature).

o An analog channel, 0-5V, 8 bit quantizing, 10 hertz sample rate. An index pulse is also supplied which can be used to advance a user supplied analog multiplexer to allow measuring a large number of parameters.

In order to provide low cost, quick reaction, and increased autonomy for the customer, SPOC has been implemented with a transparent data system concept (fig. 3). The Customer provided Ground Support Equipment (CGSE), associated software, and personnel can be used to generate commands to the customer's payload and display data from the payload during payload to carrier integration and verification testing and also during flight operations. The asynchronous data and command interfaces, and medium-rate data interface are transparent in that the interface between the customer's flight hardware and the carrier is identical in electrical characteristics and protocols to the corresponding interface between the SPOC GSE and the CGSE thus the GSE the customer used during development of his instrument may be used without modification during carrier integration and flight. The remaining interfaces (bi-level commands, analog channel, etc.) can also be connected but require conversion to asynchronous format at the CGSE. If desired the CGSE can also be provided with orbiter attitude and position data. These interfaces operate in real-time with transmission delays of 5-15 seconds during flight. Simpler experiments with minimal command and data display requirements can be accommodated without customer delivered GSE. All of the data is available on magnetic tape within one month after the flight.

HITCHHIKER-G MANIFESTING SCENARIO

Prospective Hitchhiker-G customers first discuss their requirements with the Goddard Project Office to determine feasibility and compatibility with the Hitchhiker-G capabilities. They then submit a Customer Payload Requirements (CPR) document to GSFC and a Request for Flight (NASA form 100) through NASA Headquarters. When accepted by Headquarters, payloads are placed in a queue system (currently being developed) and then selected for flight on a specific Hitchhiker-G mission. Sources of payloads are expected to include NASA sponsored, DoD sponsored, participants in NASA Joint Endeavor Agreements or Foreign cooperative agreements, and (when pricing policy is completed) other customers. Prices for commercial use of Hitchhiker-G haven't been finalized but are expected to be on the order of several hundred thousand dollars for a one port payload.

Approximately 8 months before flight the customer delivers complete documentation on his payload to GSFC. The safety data package requirements are similar to GAS in the case of canister payloads but are somewhat more complex if the customer's equipment will be plate mounted. About 4 months before flight the customer's hardware is delivered to GSFC and with the help of the customer and his CGSE the payload is integrated to the carrier, and system functional tests and EMI tests are performed. Prior to delivery the customer is responsible for performing any necessary tests required for safety certification (such as static load tests) as well as any tests required by the customer to confirm proper operation (such as vacuum or vibration tests). Following tests at GSFC the integrated payload is shipped to Kennedy Space Center and integrated into the orbiter where only interface verification tests are performed. Launch occurs typically about 8 weeks after orbiter integration. During flight the Hitchhiker-G is operated from a control center at GSFC with participation of the customers and their CGSE. Displays of orbit position, attitude, ancillary data, and any downlink TV are provided along with access to crew voice transmissions. Following landing the Hitchhiker-G is removed and de-integrated and the customer hardware is returned to the customer at GSFC.

HITCHHIKER-G MISSIONS

The Hitchhiker-G1 payload (fig. 4) flew on STS 61C in January 1986. The customer payloads were: The USAF Particle Analysis Cameras for Shuttle (PACS) which was designed to make photographs of particle contamination in the vicinity of the orbiter; The NASA/GSFC Capillary Pump Loop (CPL) experiment which determined the zero-gravity performance of a proposed Space Station thermal system; and the NASA/Perkin Elmer Shuttle Environmental Effects on Coated Mirrors (SEECM) experiment which studied the effects of residual atmosphere on telescope mirror contamination. The PACS consisted of a stereo camera and flash assembly mounted on the upper portion of the plate. The CPL instrument was carried in a sealed canister and was connected to multiple power ports to allow over 1000 W of power to be used. The mission was successful and the experimenters are currently studying their data. The carrier operated nominally with over 800 commands being sent and over 120 hours of data obtained. A number of minor ground system problems are being corrected for the subsequent flights.

Hitchhiker-G2 will carry a USAF/NRL Ultraviolet Limb Imaging Experiment (UVLIM) which will scan the horizon to obtain data on the constituents of the atmosphere; the NASA/GSFC Pumped Two-Phase (PTP) experiment which will test Space Station thermal control equipment; and a NASA/JSC Plasma Motor Generator experiment which contains a probe to be ejected from a canister during the flight.

FUTURE ENHANCEMENTS UNDER STUDY

The following are enhancements which may be added to the SPOC system in the future depending on demand and feasibility:

o An ejection mechanism to allow deployment of small probes or spacecraft from the canister. This would be similar to the existing GAS system except that power and electrical services could be obtained prior to launch via an umbilical connector. Spin-up capability is also being studied. Payloads up to 150 lbs. could be accommodated.

o A larger canister with ejection mechanism for larger attached or ejected payloads up to approximately 350 lbs. and 30 inches in diameter.

o A method for late installation of payloads into motorized door canisters on the launch pad to reduce the time-to-launch from 8 weeks to 2-3 days.

o A probe bus for ejectable experiments is being considered. This bus would be ejected from a canister, contain batteries, data system, transmitter, and receiver and would carry a customer's instruments for a brief mission in the vicinity of the orbiter while communicating to an antenna and SPOC port on the attached carrier.

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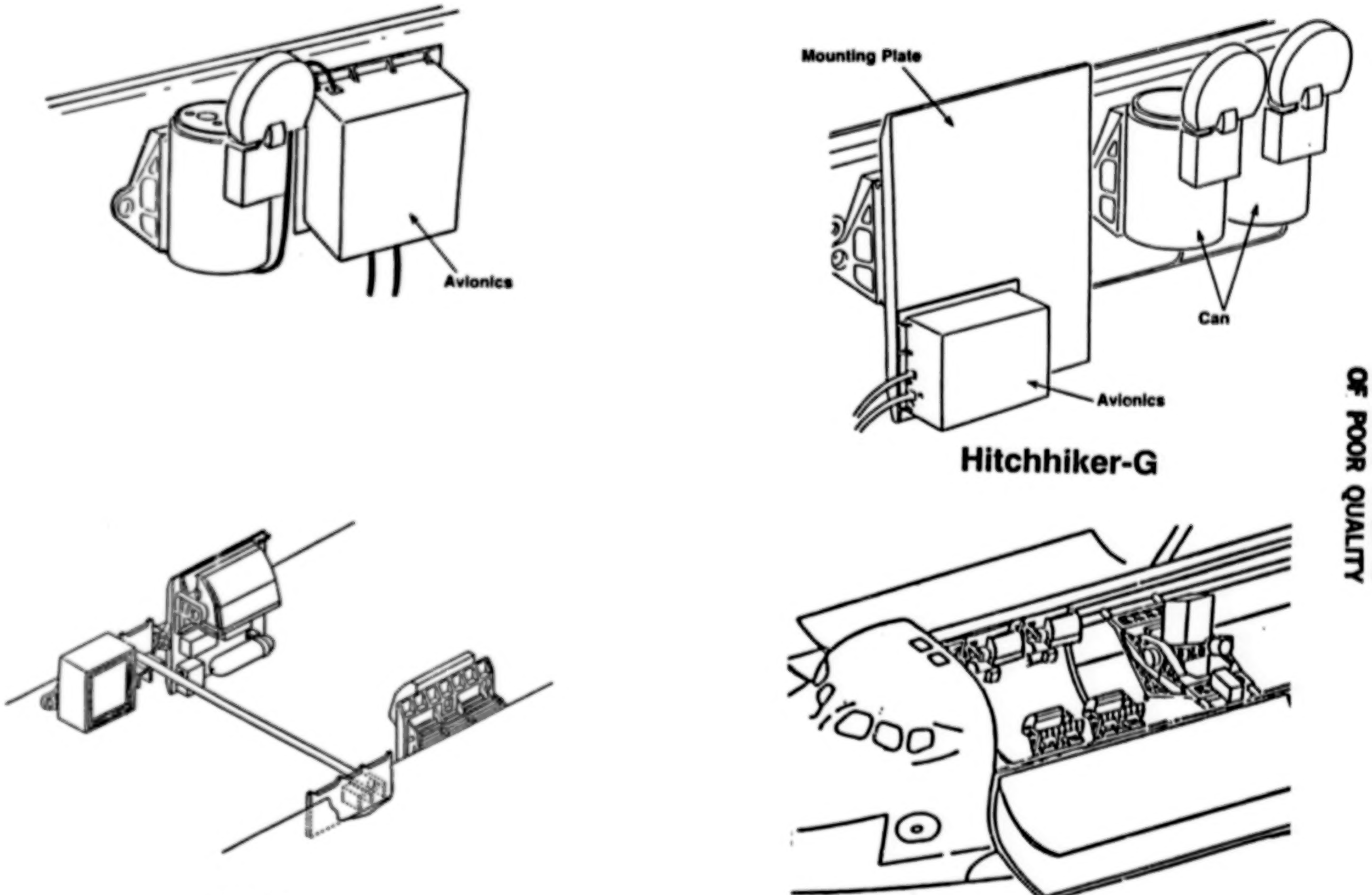

Hitchhiker-G

SHEAL I

SHEAL II

Fig. 1 SHUTTLE PAYLOAD OF OPPORTUNITY CARRIER CONFIGURATIONS

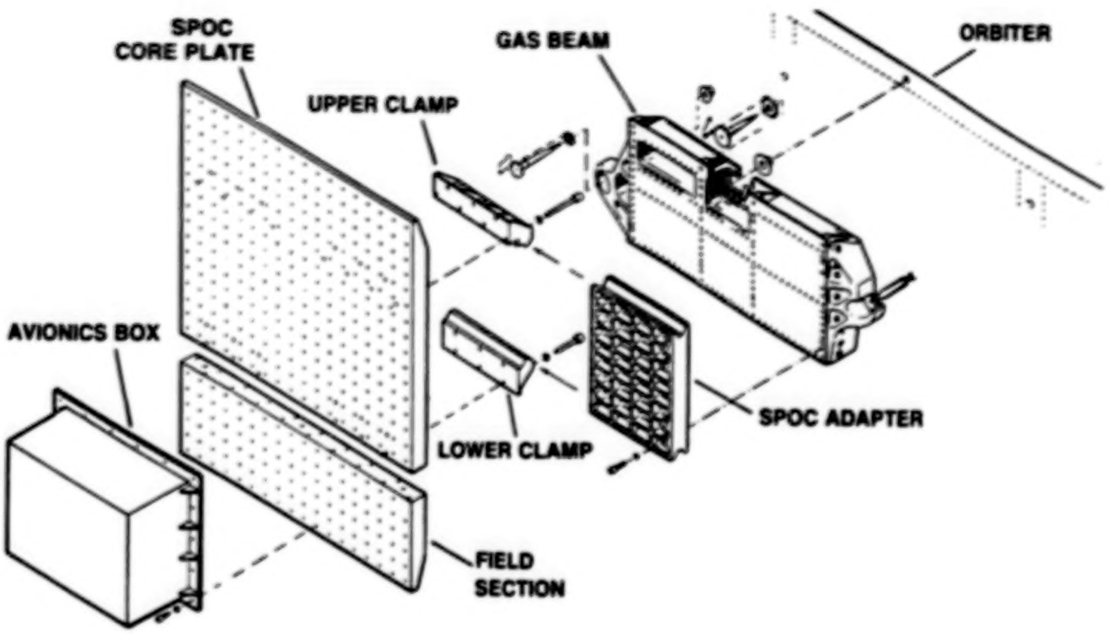

Fig. 2 SPOC PLATE

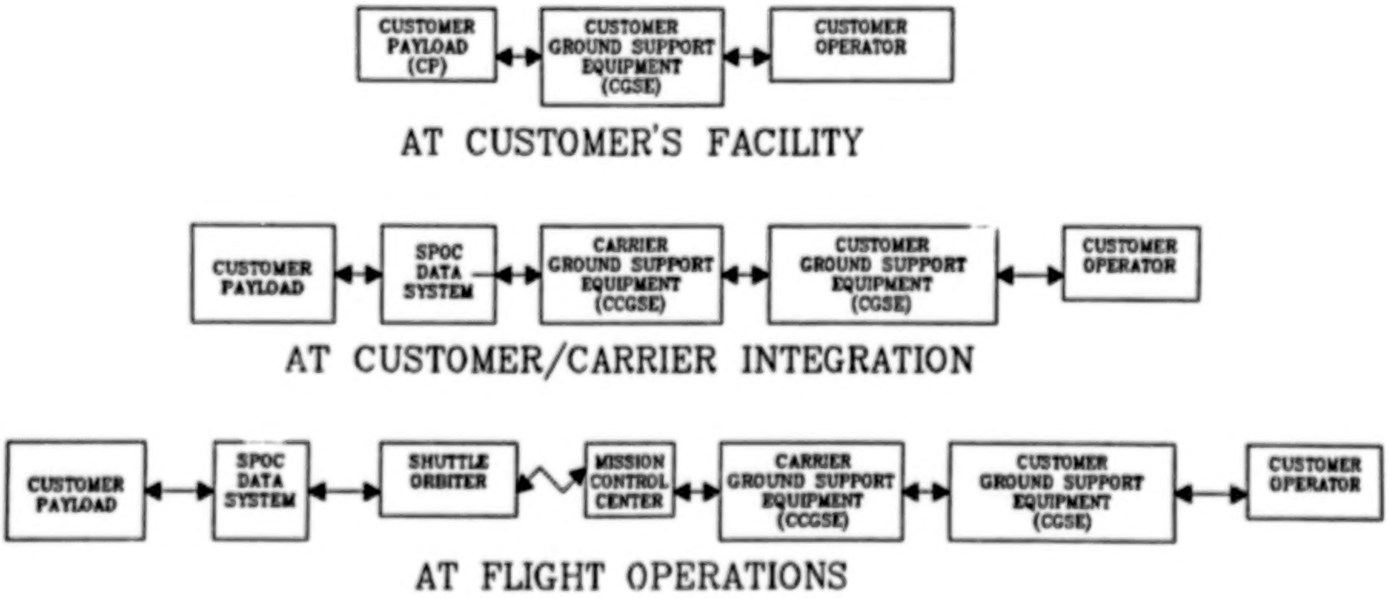
CUSTOMER PAYLOAD (CP)
CUSTOMER GROUND SUPPORT EQUIPMENT (CGSE)
CUSTOMER OPERATOR
AT CUSTOMER'S FACILITY
CUSTOMER PAYLOAD
SPOC DATA SYSTEM
CARRIER GROUND SUPPORT EQUIPMENT (CCGSE)
CUSTOMER GROUND SUPPORT EQUIPMENT (CGSE)
CUSTOMER OPERATOR
AT CUSTOMER/CARRIER INTEGRATION
CUSTOMER PAYLOAD
SPOC DATA SYSTEM
SHUTTLE ORBITER
MISSION CONTROL CENTER
CARRIER GROUND SUPPORT EQUIPMENT (CCGSE)
CUSTOMER GROUND SUPPORT EQUIPMENT (CGSE)
CUSTOMER OPERATOR
AT FLIGHT OPERATIONS

Fig. 3 SPOC TRANSPARENT DATA SYSTEM COMMUNICATIONS

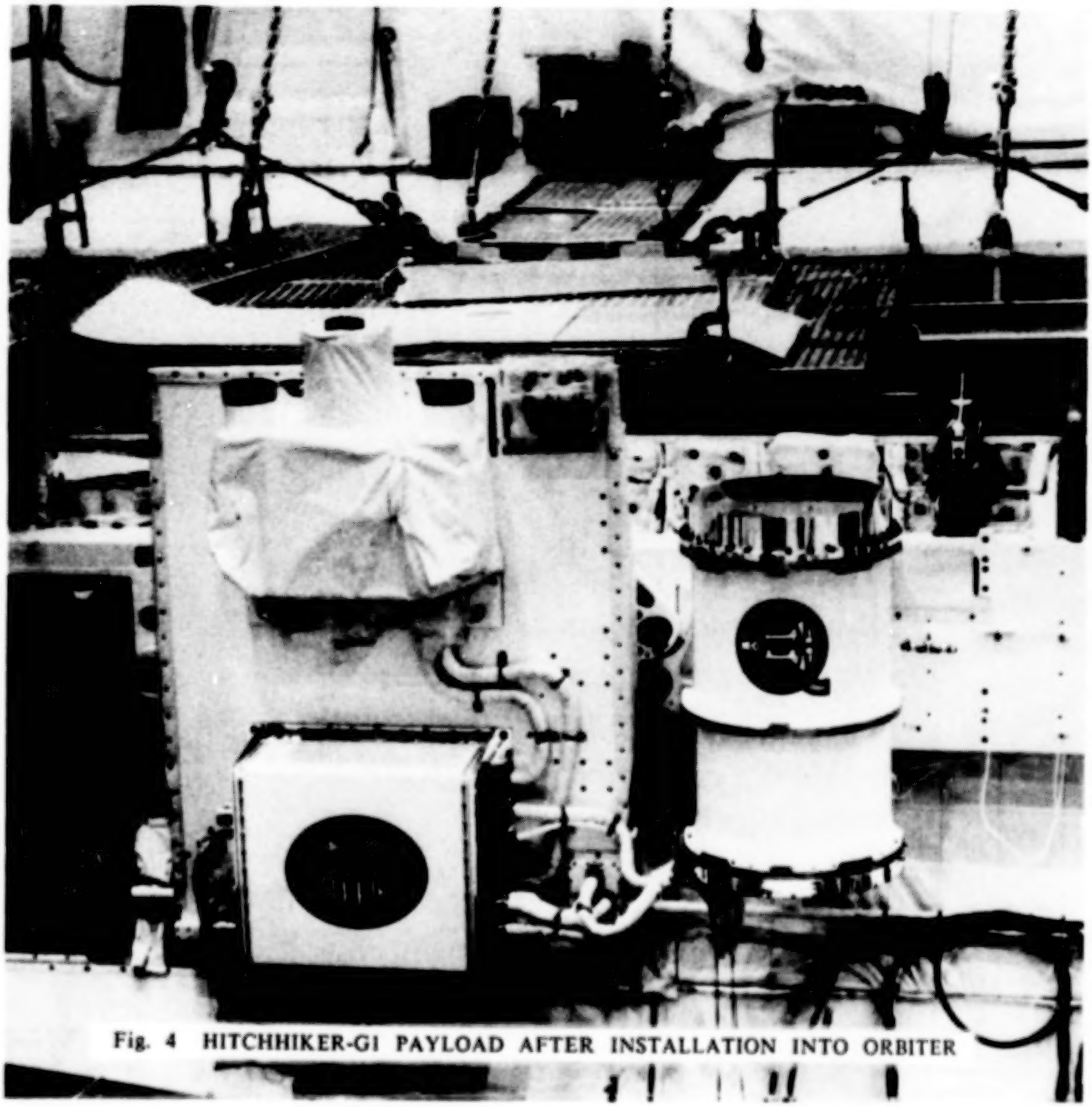

Fig. 4 HITCHHIKER-G1 PAYLOAD AFTER INSTALLATION INTO ORBITER

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Multipurpose Microcontroller Design for PUGAS II

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Abstract

This paper will report on the past year's work on the development of the microcontroller design for the second Purdue University small self-contained payload. A first report on this effort was given at last year's conference by Ritter (1985). At that time, the project was still at the conceptual stage. Now a specific design has been set, prototyping has begun, and layout of the two-sided circuit board using CAD-techniques is nearing completion. A redesign of the overall concept of the circuit board was done to take advantage of the facilities available to students. An additional controller has been added to take large quantities of data concerning the shuttle environment during takeoff. The importance of setting a design time-line is discussed along with the electrical design considerations given to the controllers.

INTRODUCTION

This canister is Purdue's second venture with the Small Self-Contained Payload (SSCP) program. Both canisters will have in common the fact that they were controlled by a microprocessor-based electronics system. This is common to many Shuttle canisters. In our second design of a canister controller, we have taken advantage of new technologies available since the first Purdue canister was designed, and of new facilities provided for the students on campus. Specifically, the use of a low-power CMOS version of the popular Intel 8085 microprocessor, and a Computer-Aided-Design (CAD) system belonging to the School of Technology has greatly eased our design process.

OVERVIEW

The experiments planned for the payload include a particle detection block, a floppy disk block, a foam metal furnace and a moisture desorption chamber. Also, because the canister support structure is being built from a foam-resin compound, it is being considered as an experiment. Its physical response to the actual lift-off vibration will be recorded.

The first two experiments are passive and will require no inflight control. The desorption experiment requires only the opening and closing of a single valve. As support for these three experiments, temperature data will be taken from various parts of the canister over the duration of the time in space. This will record any abnormal conditions that might affect the materials used. It will also report on the efficiency of the passive thermal control system, which is based on a phase-charge in a high heat capacity salt.

The foam metal furnace heating procedure requires the most complicated control. This experiment consists of melting a sample of tin and zinc carbonate. The zinc carbonate will decompose into carbon dioxide which will diffuse homogeneously through-out the sample resulting in a new "alloy" with desireable weight and strength qualities for space construction. This experiment will be tied to one of the three relays under astronaut control. They will activate this relay when NASA can guarantee a 5-15 minute period of no vibration (i.e., no attitude control thrusts or orbital manuvering). The experiment requires both control actions to be taken and data to be stored. The current to the furnace must be regulated to melt the sample as smoothly as possible. One control line will turn the current on or off. This will be cycled to provide smooth temperature regulation. The controller will monitor the output from several temperature sensors to provide a thermostatic control. The heating cycle is not a simple on-off operation. Rather, for the experiment to work properly, the metal sample is brought up to a pre-selected temperature, held there for a few seconds and then allowed to cool.

Data will be stored from the temperature sensors for analysis later on the ground. The data will be taken very slowly prior to heating to establish initial conditions. Then as the critical heating point is reached, data will be taken at a faster rate. As the furnace cools, data will again be taken at a slower rate. Data will also be taken from a triaxial accelerometer during the melting and cooling in case the shuttle does experience some acceleration. This will be correlated with any anomolies in the metal sample.

Collecting the structure data has a requirement that increases the difficulty of implementation: the system must sense the time of lift-off without any signal from the shuttle crew. The most obvious indication of lift-off is the sudden increase of vibration. As this lift-off vibration is to be used as the signaling factor, vibrations from handling must be ignored by the controller. This is a critical decision for the hardware to make for if the wrong decision is made as to the validity of the collected data, the experiment will be a failure.

DESIGN DEVELOPMENT

At the commencement of this design, the following considerations were kept in mind. A system is needed to provide precise, reliable control of a variety of experiments. This system must be able to monitor the canister conditions, make decisions and store data for retrieval after the shuttle returns to Earth. Because Purdue hopes to continue its involvement with the SSCP program, it would be desirable that the final design could be easily adapted to future needs. Time would be saved if a system was designed using materials with which students were already basically familiar. It was decided that a single board micro-computer met the above requirements in the best manner when also considering space, weight, and power.

Reliability was a major concern in this decision. The use of a single control system has the drawback that one fault can jeopardize the entire canister results. An initial choice was made to have a controller for each experiment with a master system guiding them and watching for any malfunction. This idea was dropped for two major reasons. First, hardware interfacing and software for the master controller would be a monumental task to complete and to guarantee to work under a variety of conditions. Second, a failure in only the master system could still accidentally shut down all of the individual controllers. Our final design uses only the three independent controllers, with one each for the structure, furnace, and desorption chamber. The desorption controller will also take canister temperature data for the duration of the flight. If one of the controllers malfunctions, only part of the canister's experiments will fail.

The controller taking the temperature data will run from five to seven days. Even at the low levels of power used by integrated circuits, over this period of time the total is large. Because batteries make up the majority of the bulk of the canister's weight, low power usage is a must. For this reason it was decided to use CMOS integrated circuits. Since the flight of Purdue's first canister in 1983, a CMOS version of Intel's 8085 microprocessor and related family of circuits has been introduced. In addition, Purdue currently uses the 8085 for its introductory microprocessor course. Thus, many of the students involved in the controller hardware and software design are already familiar with the 8085.

The basic design, shown schematically in Fig. 1, includes the 8085, 8k of ROM for the software, 8k of EEPROM for data storage, an eight bit analog to digital converter, a mc146818 real-time clock for system timing and an 8155 which provides 256 bytes of RAM, a timer, and three input/output ports. External communication is done through one of the ports on the 8155. Adding a communications chip to the prototype to ease the loading and debugging of software was considered. However, it was felt that the prototype should be an exact duplicate of the final flight hardware. In this way there would be little doubt that the final version would work.

Another of the ports of the 8155 is used as an internal control signal generator. The EEPROM selected has six modes of operation, including various write and erase modes as well as read. The select lines to choose one of these states come from this port. This eliminated the need for complex decoding of address lines to select the proper functions. This produced the benefit of reducing the random logic to a level where it can be programmed on one Programmable-Array-Logic chip instead of using several generic chips. This reduces power and space and increases reliability.

The timer of the 8155 performs a very important function as a "watchdog". The controller microprocessors are exposed to a very rugged and unpredictable environment. If the processor were to "glitch" due to a transient in the power supply or radiation, its internal registers might be altered. The processor might freeze up, execute non-program data or do any number of unpredictable actions. The timer output is connected to one of the interrupt pins of the 8085. The software will be written in such a way that when a procedure has been completed, a flag will be set and the processor will pause. The timer will bring the processor out of the pause and check the flag. If the flag was set then the software has probably been running correctly. If the flag is not set then the interrupt routine will try to recover from the error.

It is felt that the only way to insure that the returned data in memory is valid is to keep a log record of all actions taken in the EEPROM. If power is removed or the controller stops for some reason then it will be known exactly where this occurred. The watchdog routine will also use this log to determine the status of the system before an error occurred. The log entries will include the time from

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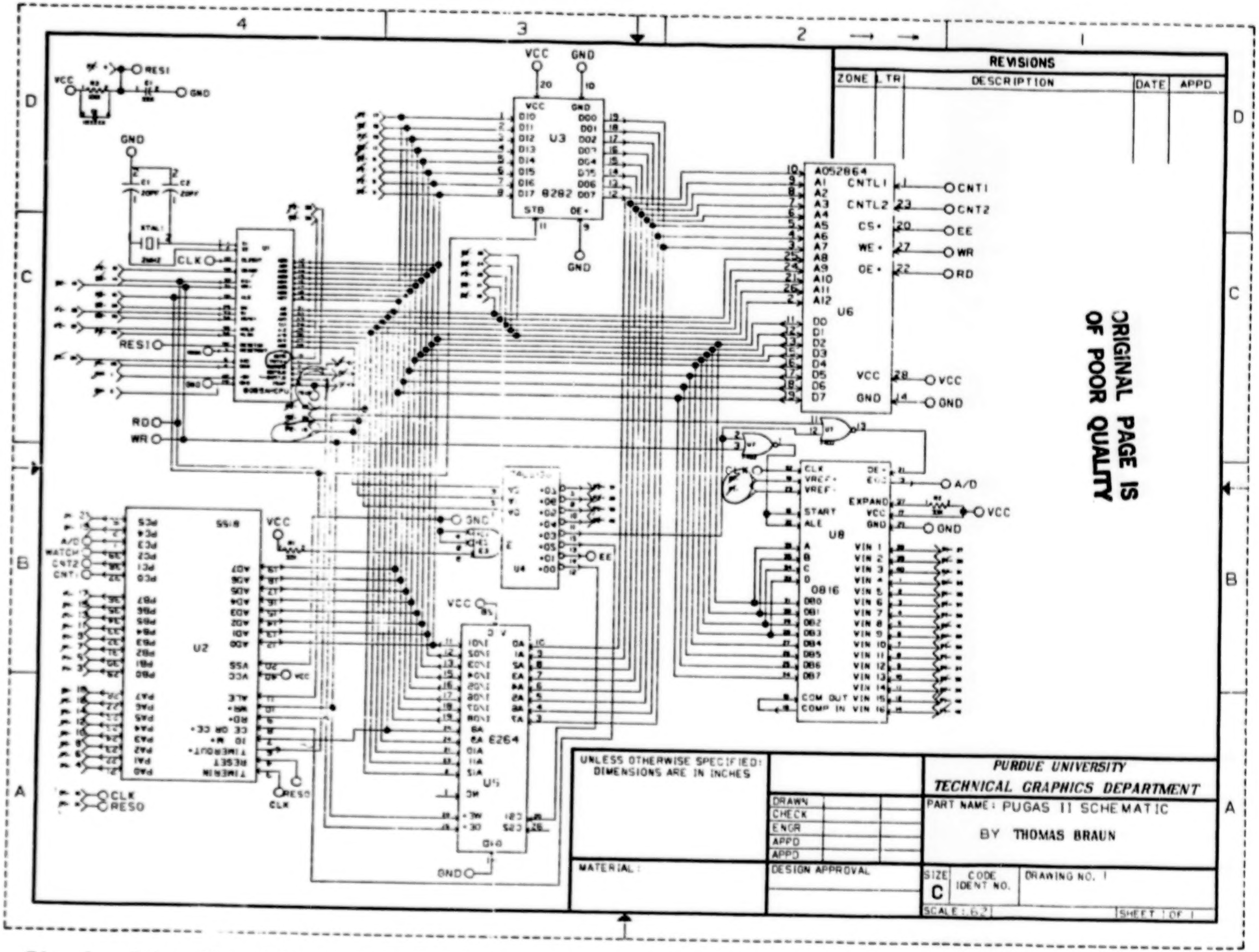

Fig. 1. Schematic of the prototype multipurpose microcontroller for PUGAS II.

the real-time clock chip and a code for the action completed.

The furnace and desorption controller are identical. The structure controller has been modified to perform its special function. To study the response of the structure to vibration, Fourier analysis will be performed on the data taken from strain gauges mounted on the structure fins. This requires that the sensors be sampled at least 8000 times per second. This is to avoid problems in the analysis with high frequency vibration. As sixteen channels are to be monitored, the resulting 128kHz sampling rate is beyond the ability of the microprocessor and single A/D converter system. An 8257 direct memory access chip will be used to bypass the processor and directly transfer data from a group of A/D converters to a set of banked memory blocks. The huge amount of data recorded will require at least 128k of battery backed-up memory. This memory will be selected in 32k blocks by the same 8155 port that controls the EEPROM.

Of great concern is the backing up of the memory. EEPROM memory is too slow to use for this application and would require a large number of chips. A combination of a battery and five Farad capacitors will be used to backup static memory chips. A very simple analysis of the data will be done in space and stored in the EEPROM so that data will be retained if the memory fails.

To activate the controller, a set of vibration switches will trigger an SCR switch. This device will latch power to the controller until it is shorted out under software control. In series with the trigger switches is a mercury switch. Because the canister is stored vertically but launched almost horizontally, this switch will be mounted at an angle that prevents ground shocks from activating the experiment. An additional safety measure will be a pressure gauge. This gauge will be vented to the outside of the canister. If the pressure drops, then it will be assumed that the shuttle is climbing into space. Once the software has determined that good data has been measured and has done the preliminary analysis, the processor will turn itself off permanently. This will be done by blowing a small fuse on the power supply line. In this way this unit cannot be reactivated. If the controller is activated accidentally, it will temporarily shut off by shorting the SCR. This will break the connection. The controller can still be reactivated by the next shock.

The vibration experiment was originally designed as a separate circuit board that would piggyback to a controller identical to the others. Through the use of the CAD system, the design was stripped of the unneeded slow A/D converter and the real-time clock and condensed to one circuit board. Because the CAD computer can easily generate the modified circuit board patterns, custom design of the third controller was a practical consideration. This would not be practical if the drawing was to be done by hand.

All of the controllers will be able to communicate to the outside of the canister through the 8155 port. This is essential so that the computer hardware can be checked after it has been installed into the NASA canister at the launch site. The software will include routines to check the hardware and sensors. This will be done through the use of an IBM PC as a terminal for the controllers. The first action a controller will take upon being activated will be to check a control line to see if it is in space or on the ground for testing.

PRESENT STATUS

Most of this design work was done by the spring of 1986. Due to the fact that this is a student project, there is a continuous influx of new workers. New members bring in new ideas and methods of doing things. We found that to keep the project moving at the necessary pace, a date needed to be set after which no changes would be done to the design. Doing this generated the necessary activity to complete the design. Setting such dates is important if work is to be completed.

Currently, we are in the process of designing and choosing sensors, and writing software. Because the controllers are essentially identical, most of the software will be common to all of them. This includes such routines as the watchdog check, communications, log updating, and system timing. Rules are being generated for the code that governs the unique operations of each controller. These vary from being simple for the desorption controller to very complicated for the structure experiment. A prototype has been built and is being debugged. We hope to have all of the controllers completed by the end of the year.

ACKNOWLEDGEMENTS

The project team members would like to thank Dr. Harold Ritchey for donating the canister reservation to Purdue and Dr. John Snow, our faculty advisor, for his help and guidance. Ms. Helen Henry assisted by typing this manuscript.

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Title: Geotaxis Baseline Data for *Drosophila*

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Abstract

Geotaxis profiles for 20 *Drosophila* species and semispecies at different ages have been examined using a calibrated, adjustable slant board device. Measurements were taken at 5° intervals ranging from 0° to 85°. Clear strain and species differences are observed, with some groups tending to move upward (- geotaxis) with increasing angles, while others move downward (+ geotaxis). Geotactic responses change with age in some, but not all experimental groups. Sample geotaxis profiles are presented and their application to ecological and aging studies are discussed. Data provide a baseline for future evaluations of the biological effects of microgravity.

Introduction

Geotaxis is defined as directed movement mediated by gravity. Since the early twentieth century, geotaxis in insects (*Drosophila* in particular) has been used as a model system for investigating a diversity of biological problems including:

1. effects of environmental cues on behavior (Carpenter, 1905),
2. receptor function and mechanisms of sensory systems (Horn, 1975),
3. genetic architectures underlying behavior (Hirsch, 1959; Dobzhansky and Spassky, 1962; Walton, 1968; Woolf et al., 1978),
4. learning capabilities in insects (Murphey, 1969),
5. behavioral bases for ecological differences among species (Fogleman and Markow, 1982) and between life stages of the same species (Markow, 1979),
6. aging processes and senescence (Herman et al., 1971; Miquel et al., 1976; 1979; Leffelaar and Grigliatti, 1984a,b).

In studies of aging, changes in geotactic response have provided biological markers for:

a) identifying aging individuals,
b) examining the effects of environmental factors on aging individuals,
c) determining the physiological basis of behavior loss in aging individuals,
d) localizing changes at the cellular and molecular levels that accompany such behavior losses,
e) identifying genetic mutants that alter aging patterns.

Despite the broad array of questions that can be addressed using *Drosophila* geotaxis in experimental paradigms, problems in the interpretation of results may become evident. It is known, for example, that geotactic response can be a function of the apparatus being utilized, and that different components of the response may be reflected by each experimental design (Murphey and Hall, 1969; Grossfield, 1978; Levine et al., 1981). Therefore, species, strain and age comparisons of geotactic responses remain tenuous as long as different laboratories measure geotaxis in different ways.

The present series of experiments represents the most extensive body of work known which has utilized identical experimental methodology for all subjects. Direct interspecific comparisons can be made among 20 species and semispecies, strains can be compared within many of these groups, and age comparisons can be compared within many of these groups, and age comparisons can be carried out for all. Additionally, direct comparisons are now possible between flies representing different degrees of phylogenetic relatedness, as well as between flies representing different ecological backgrounds (see Table 1).

Methods and Materials

Animals and Housing

Drosophila species, semispecies, strains and test ages are listed in Table 1. All flies were reared on a raisin-based culture medium at 19-20C, 67%RH and constant light.

Experimental Procedures

Flies aged 1-2 days, 7-9 days and 30-36 days were tested separately in the rearing chamber. A test lasting 62.5 min began after 20 individuals were aspirated into the center of a 30cm glass tube marked on the outside into three equal sections. The tube was placed on an adjustable board calibrated for angles ranging from 0° to 85°. A maximum of nine tubes were tested concurrently. Starting at 0° and ending at 85° the board was raised 5° every three minutes. After each three minute interval, the number of flies in each third of the tube was counted. Additionally, each time before the board was raised, it was held at 5° and dropped in order to dislodge flies from their previous position, and then raised to 45° so that flies would start from the bottom when the board was set at the new test angle. This was done because pilot work indicated that a) when flies were not dislodged each time, they would often distribute themselves in the tube and remain motionless for much of the test period, and b) after being dislodged, those flies raised to steep angles would slide to the bottom of the tube while those raised to less severe angles did not. 30 replicate tests were carried our for each experiment.

This test procedure provides information about the minimum angle required to elicit a geotactic response (geotactic sensitivity), and the effects of 18 experimental angles on the tendency to move in a particular direction (geotaxis profile). Measurements can be taken in ascending, descending or random order of presentation of angles.

Analysis of Data

Intraspecific. The mean number of flies (± S.D.) in each section of the tube at all 18 experimental angles was calculated for each species, strain and age group (based on 30 replicates of 20 flies each). At each experimental angle, the mean number of flies in the top and bottom sections of the tube were compared using the Chi Square test (df=1) with the Yates correction for continuity (Zar, 1974). Angles at which these means became significantly different were recorded. Using this method, age groups and/or strains can be compared at any angle or set of angles.

Interspecific. The mean number of flies in the top or bottom of the tube can be compared among any two or more species at any experimental angle using Students's t-test. Thus, species differences at any age can be directly compared.

Table 1. Drosophila Subjects Tested For Geotactic Sensitivity and Geotaxis Profiles.

Subgenus	Species Group	Species (# strains)	Ecological Background (Throckmorton, 1975)	Ages Tested (days)
Drosophila	Funebris	funebris (1)	cosmopolitan	1-2, 7-9, 30-36
	Immigrans	immigrans (1)	cosmopolitan	1-2, 7-9
	Repleta	arizonensis (3)	desert	1-2, 7-9, 30-36
		mojavensis (3)	desert	1-2, 7-9, 30-36
		mulleri (1)	desert	1-2, 7-9, 30-36
	Robusta	robusta (1)	temperate forest	1-2, 7-9, 30-36
	Virilis	virilis (1)	temperate forest	1-2, 7-9, 30-36
		americana (1)	temperate forest	1-2, 7-9, 30-36
		montana (1)	temperate forest	1-2, 7-9, 30-36
Sophophora	Melanogaster	melanogaster (2)	cosmopolitan	1-2, 7-9, 30-36
		simulans (2)	cosmopolitan	1-2, 7-9, 30-36
		ananassae (1)	cosmopolitan	1-2, 7-9, 30-36
		takahashii (1)	subtropical forest	1-2, 7-9, 30-36
	Obscura	obscura (1)	temperate forest	1-2, 7-9, 30-36
		pseudoobscura (1)	temperate forest	1-2, 7-9, 30-36
		miranda (1)	temperate forest	1-2, 7-9, 30-36
	Willistoni	paulistorum		
		*Amazonian (1)	tropical forest	1-2, 7-9, 30-36
		*Interior (1)	tropical forest	1-2, 7-9, 30-36
		*Transitional (1)	tropical forest	1-2, 7-9, 30-36
		*Centroamericana (2)	tropical forest	1-2, 7-9, 30-36

* semispecies

GT Ratio. In order to facilitate comparisons, results from all experimental groups were quantified and graphically described using a ratio introduced by Bean (1977). GT is a dimensionless ratio expressing the proportion of the half-tube population of flies that has undergone a net redistribution between halves of the experimental tube at each angle. The ratio takes on values from -1 to +1, where the sign corresponds to the direction of movement. Nagative values reflect net upward movement of flies (negative geotaxis represents movement away from the force of gravity). Since calculation of the GT ratio requires the number of flies in each half of the tube, the flies observed in the middle third of the experimental tube were equally divided between top and bottom halves.

Results and Discussion

Figs. 1 and 2 present a sample of geotaxis profiles and how such data can be applied to a variety of biological questions.

Ecological Studies

Fig. 1a reflects the geotaxis profiles just after eclosion (1-2 days of age) for three desert species, *D. arizonensis*, *D. mojavensis* and *D. mulleri*. *D. arizonensis* and *D. mojavensis* are closely related sibling species that feed and breed on columnar cacti, whereas *D. mulleri* is found on the lower growing prickly pear cactus, *Opuntia* (Zouros, 1973). *D. mulleri* shows a clear positive geotactic tendency which corresponds to its preference for the ground-dwelling *Opuntia*. By contrast, the negative geotaxis of *D. arizonensis* would enable it to utilize its primary resources growing higher. The tendency of *D. mojavensis* to show neither preference may reflect a means of reducing competition with its close relative, *D. arizonensis*, when they occupy the same resources.

Fig. 1b reflects the geotaxis profiles of three tropical *D. paulistorum* semispecies, Transitional, Amazonian and Interior. The distributions and temperature capabilities of Amazonian and Interior often overlap, whereas those of Transitional are quite different (Schnebel and Grossfield, 1984, 1986a,b). Since Amazonian and Transitional are rarely found together, their similar geotactic tendencies are not expected to create situations of resource competition. However, the potential for competition between Amazonian and Interior is great, and their different geotaxis profiles represent a mechanism for vertically partitioning resources.

Aging Studies

D. melanogaster is the most commonly used species other than humans in studies of aging and senescence. Figs. 2a,b show the geotaxis profiles of two strains of *D. melanogaster* as individuals grow older. The Florida strain (mel-F) appears to lose its negative geotactic tendency by the third test age (30-36 days). The Oregon-R strain (+/+) shows a similar change, but the loss of geotactic response already occurs by the second test age (7-9 days). Structural comparisons of the two strains at critical ages could reveal underlying differences contributing to such age effects. A complementary approach in which *D. melanogaster* strains are compared with closely related species showing no effects of aging on geotaxis (Fig.2c: *D. simulans*) could prove equally informative.

In addition, since the genetics of *D. melanogaster* are well understood and its chromosomes have been mapped, the search for mutants affecting geotaxis in these strains may be profitable in analyzing the genetic and molecular bases of aging processes influencing this system.

Fig. 1. Sample Geotaxis Profiles: Ecological Studies.

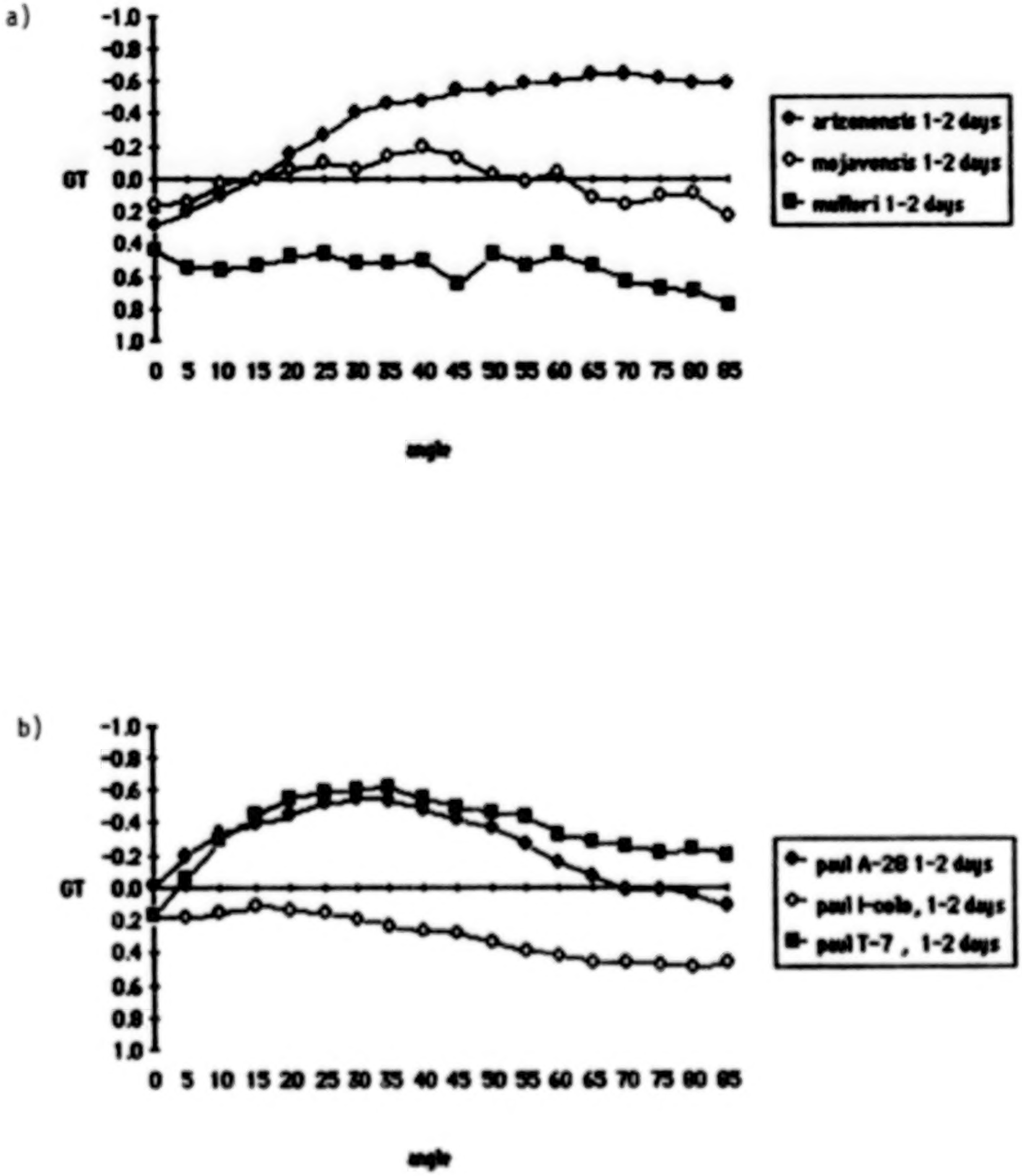
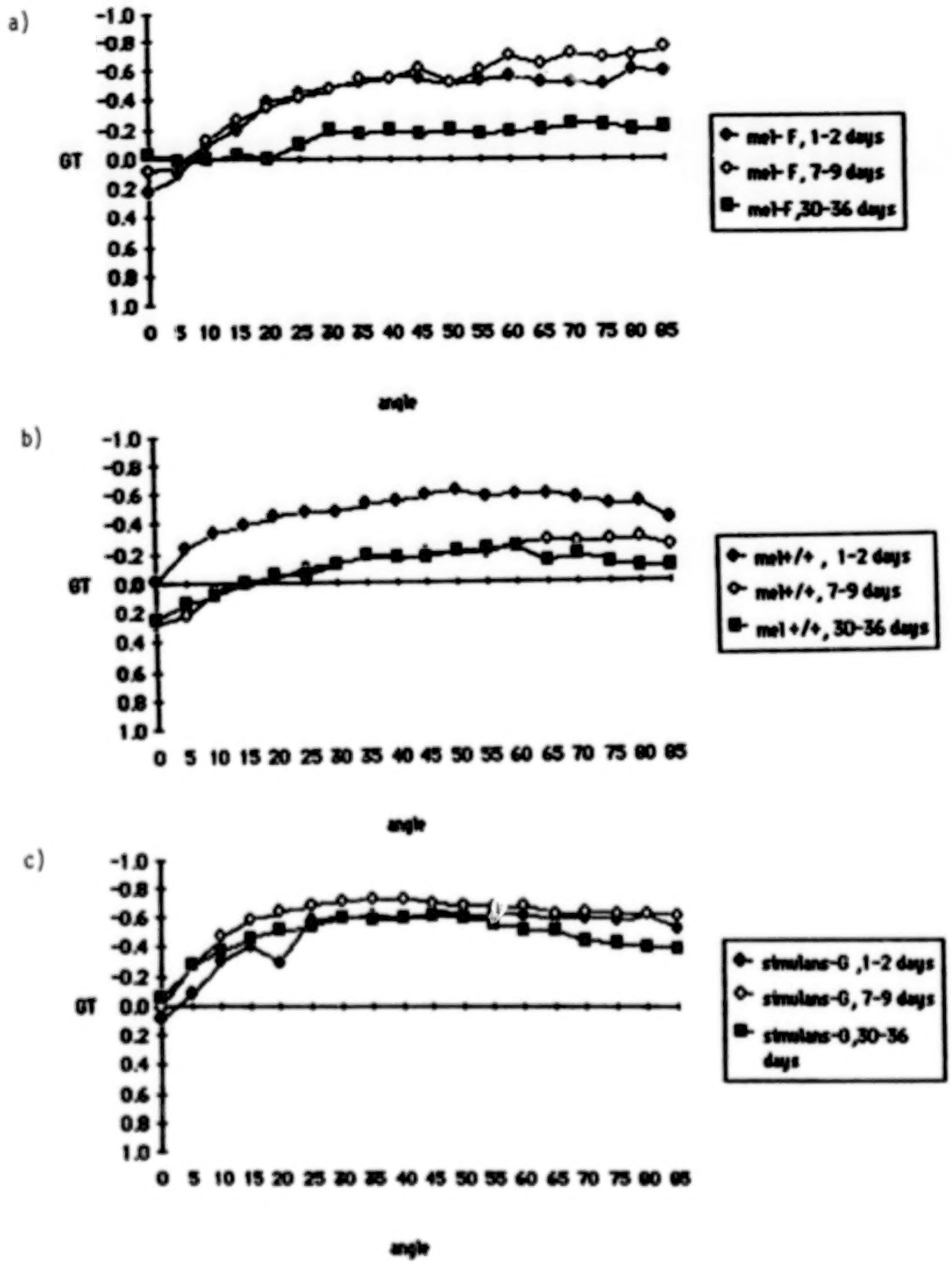


Fig. 2. Sample Geotaxis Profiles: Aging Studies.



These data demonstrate the applicability of the *Drosophila* geotaxis system for addressing questions of biological importance. The broad range of subjects investigated here under identical experimental conditions provides a foundation for direct systematic comparisons among different species, strains and age groups. These attributes make the present work invaluable for providing baseline data that can be used in future evaluations of the biological effects of microgravity.

Acknowledgments

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GET AWAY SPECIAL EXPERIMENTERS SYMPOSIUM
OCTOBER 7-8, 1986
GODDARD SPACE FLIGHT CENTER

MARSHALL AMATEUR RADIO CLUB EXPERIMENT (MARCE) POST FLIGHT DATA ANALYSIS

by

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ABSTRACT.

This report briefly describes the Marshall Amateur Radio Club data system, the data that was recorded during the flight of STS-61C, the manner in which the data was reduced to engineering units, and the performance of the student experiments determined from the data.

MARCE DATA SYSTEM.

A detailed description of the data system is presented in the Safety Data Package and will only be summarized here. The system is a specially designed single board computer employing National Semiconductor Corporation's (NSC) NSC800™ CMOS microprocessor, an NSC Digitalker™ subsystem, analog to digital converters, and input/output ports. The purpose of the system is to acquire housekeeping data during the flight and to sequence the operation of the student experiments. In addition, a specially designed analog circuit is provided to monitor the silver-zinc battery temperature for safety purposes. Secondary monitoring of the temperature is provided by one of the analog to digital converter (ADC) channels. MARCE also provided safety backup for disabling the ovens in Experiment 1, and a bias voltage for the crystal growth cell of Experiment 3. A pressure transducer is included which allows the data system to inhibit the transmitter to preclude corona in the event of a pressure leak. The battery voltage is monitored by an ADC channel so that the computer can drop all loads if the battery voltage decays. A secondary voltage sensor is provided by the Schmitt trigger action of the NOT-RESET INPUT of the microprocessor. A block diagram of the data system is shown in Figure 1.

This Get Away Special (GAS) flight was unique in that an amateur radio transmitter was included to send real time status of experiment operation to the ground. Radio amateurs around the world were requested to tune in to the transmissions and record the data for relay to the Marshall Amateur Radio Club. The facilities of the Amateur Radio Satellite Corporation (AMSAT) were the focal point for the near real-time signal reports. The results of the amateur radio portion of the experiment were highly successful and will be reported in a separate document.

Early in the development of MARCE, a decision had to be made to use an available set of hardware or design a new system from scratch. The available hardware did not include a Digitalker subsystem and would have required integrating separate printed circuit boards for the micro-processor, memory, analog converters, and input/output ports. In addition, there was no volunteer experienced in programming the micro-processor. Finally, mother board systems are always suspect because of the large number of connector pins involved.

A relatively new CMOS microprocessor chip set was available from National Semiconductor which has the 8080 microprocessor bus structure but uses the Zilog Z80™ instruction set. An analysis showed all the required functions could be accommodated on one card the same size as the pre-built cards. A software development system was available for programming and the programmer was already familiar with the Z80 instruction set. The disadvantages of starting from scratch with a new chip set involve learning the pin functions and operation of the peripheral chips in the set. Even though the chip set was relatively new, the documentation was very complete and understandable. A printed circuit development system was also available which made the conversion from routing sketches to negatives a relatively painless job.

The MARCE flight program used the interrupts available in the NSC800 to allow multiprocessing. Mission elapsed time, and two serial input channels used three of the interrupts with the actual functions provided in software. These interrupts were carefully masked at the proper time to preclude external signals from taking control improperly and causing the computer to "hang up". The ADC and Digitalker subsystems were checked by software for proper operation and the software was designed to continue other functions if failures occurred in these two subsystems. The software was designed to disable safety critical functions if the ADC failed while providing safety critical measurements.

Software provided debounce protection of the GCD relays. The relays allowed the crew to trigger the operation of the ovens in Experiment 1 so the alloys would resolidify during sleep periods when crew induced accelerations are the lowest. The relays were also used to trigger additional transmission sequences providing mission flexibility. In the event the mission had to be terminated early, a switch sequence operated the second pump in the radish seed experiment inhibiting further growth.

The Digitalker speech data memory was specially programmed on a 4K byte EPROM using a speech development system. This simplified the support required of the microprocessor by allowing phrases to be spoken with a single call to the Digitalker.

A steady stream of data was generated by software to dump memory contents continuously. This data was formatted to be printable directly on a data terminal or printer operating at 300 baud. The data was not in engineering units so external processing had to be provided.

DATA REDUCTION SYSTEM

A Commodore C-128 computer was programmed to receive serial data from the MARCE data system, store the data on a floppy disk, and later convert the data to engineering units. Figure 1 describes the measurements that were recorded in the memory every 10 minutes. Voltage, pressure, and current measurements required simple linear conversion to engineering units. Temperature, measured by thermistors, was non-linear, so conversion consisted of a table lookup and interpolation routines to convert the voltage measured by the analog to digital converter first to resistance, and then to temperature. Three different sets of conversion tables were required because of the different ranges required of T1 and T2, compared to T3 through T5. Also, T6 located in the battery used a different type of thermistor than T1-T5 which required its own conversion table. Actually, it was found that the shape of the temperature/resistance curve for T6 was nearly identical to the shape of the curves for the T1-T5 thermistors so the same lookup table was used by multiplying the values by a correction factor. The results were accurate to within the published range for the battery thermistor.

DATA REDUCTION RESULTS.

A sample of the results of the data reduction are shown in Figure 2. The time is measured from the activation of the GAS by the crew and can be correlated to GMT time by consulting the crew check list. Another way to calibrate the time is using the radio down link transmission times. The transmissions begin on the minute as measured by the MARCE mission timer. The temperatures, battery voltage, battery current, and pressure are shown in degrees C, volts, amperes, and pounds per square inch respectively. The last eight columns of data is a decoding of the status word. The columns are as follows:

VTL	A 1 in this column means the battery voltage is too low and the data system has turned off all battery loads.
E23	A 1 in this column indicates that the data system has operated the camera in experiment 2 or the pumps in experiment 3.
1OT	A 1 in this column indicates the data system has detected an overtemperature condition in experiment 1 and has removed power to this experiment.
SWC	A 1 in this column indicates switch C is latent.
SWB	A 1 in this column indicates switch B is latent.
XMT	A 1 in this column indicates the digitalker has kept the transmitter on for longer than 59 seconds. This could be the result of a digitalker subsystem failure or power supply failure. The data system turns off the transmit relay and will not operate the transmitter until switch B is cycled to reset the failure indication.

PTL A 1 in this column indicates the pressure inside the GAS can is too low. The data system inhibits the transmitter until the condition is reset by cycling switch B.

ADC A 1 in this column indicates the analog to digital converter has not completed conversion of a channel within the allotted time.

The status indications remain set to one for 10 minutes on the radio transmissions even though the cause of the status might have been only momentary.

Many entries in the data have been lined out. This data has been contaminated by errors caused by cycling power on the data system. See the section on anomalies which follows.

The temperature data indicates conditions were colder than expected. The attitude of the orbiter during some of the operation was Y-axis to the sun to alleviate a thermal problem on the orbiter. The attitude timeline should be obtained before drawing any detailed conclusions from the thermal performance. The performance of the heater on the radish seed experiment (T3) was adequate for some of the mission but provided insufficient power to overcome the coldest ambient temperatures experienced. This heater was designed with a set point of about 17 degrees and had enough power to raise the experiment about 16 degrees above ambient. The heater on the crystal growth experiment (T4) failed to provide significant thermal rise. This heater was powered by a separate battery supply. The batteries were renewed before flight, but cold pad conditions might have partially depleted them. Thermal gradients between the heater and the thermistor could have resulted in an error in the measurement. Thermistors connected to experiment 1, the alloy resolidification experiment, indicated 20.0 degrees which is offscale low and a normal indication. The current measurements also indicated that experiment 1 completed the oven operations successfully.

Battery voltage was nominal throughout the mission. Even though the temperature was cold, the battery voltage did not drop more than 1.5 volts under load.

The flight plan was changed during the mission to return a day early so this GAS was turned off at an elapsed time of 79:40 as indicated by the data system. Log information shows the crew operated Switch C as provided in the Payload Accommodations Requirements prior to removing power using Switch A. This terminated the growth of the radish seeds.

Bad weather at the landing site forced a delay in the landing. This presented an opportunity to provide additional experiment time for this GAS. It was also decided to reactivate the transmitter to provide a fourth set of transmissions. Analysis of this data shows the proper switch sequence was not seen by the data system to reactivate the transmitter. It is noted that there was no documentation of the proper sequence provided in the PAR. The data system must see a latent to hot transition for transmitter reactivation. Lack of the "one" status for Switch B and absence of transmitter current shows the transmitter was not reactivated. Turn on of the package was profitable since additional time was available for additional crystal growth and addition thermal data was received. The package was again turned off at an elapsed time of 92:40.

Further delay of landing again afforded a third operational period. This time the switches were sequenced in a manner which turned on the transmitter. The status indication shows Switch B was latent, then hot, and the current indicated the transmitter was operating. The decision to turn on the package for the second and third times was welcomed by the experimenters but there was insufficient time to alert the radio amateurs in other parts of the world. Transmitter operation did serve to provide some additional heating of the experiments but the amount of this heating was only about one degree and is not really significant. The GAS was turn off for a final time at an elapsed time of 110:20. This additional time again allowed more thermal data to be taken and the crystal growth experiment was powered so additional crystals could grow. The camera for the crystal growth experiment was not operated for the second and third operating periods as planned.

ANOMALIES.

Anomalies pertaining to the experiments as noted in MARCE data were reported above. This section will deal with data system anomalies. Actually, operation of the data system as a sequencer was nominal. The only anomaly to report is errors in data. During the thermal tests, some RAM data was corrupted by switching transients. A bypass capacitor on the CMOS RAM power line was thought to be too high. The value was reduced from 2.2 mfd to 0.1 mfd which shortened the turn on delay of the RAM. The fix appeared to work at room temperature but was not verified at cold temperatures. During development of a second generation data system, the problem was again observed, this time with a different type of CMOS RAM chip. More flexible checkout software was developed by this time to facilitate memory retention tests. Attention this time was focused on the cleanliness of the RAM disable signal especially during power-up and power-down. Attempts were made to trap the offending signal but these were unsuccessful. Then, the line was bypassed with a .001 mfd capacitor and the switching problem was eliminated. Evidently, the transient was being caused by the NSC810 I/O chip during the power-down sequence. The bypass capacitor shunts the short transients that were not seen on the oscilloscope. This fix should be verified by sequencing the power during thermal tests of the new system.

The errors could also be caused by radiation upset but there is insufficient evidence to support this theory. Another microprocessor with CMOS RAM was in experiment one and no abnormal data was detected in the post flight analysis of that data. The results of the GAS experiment named CRUX (Cosmic Ray Upset Experiment) will be reviewed when available to determine if the susceptability of this type of RAM warrants further analysis of this data.

The effect of the problem on the overall performance was more of an aggravation because the thermal data is changing slowly. There was no problem with the program memory because EPROM is used for storing the program.

CONCLUSIONS.

The tabular data presented in this paper had to condensed to conserve space. This data could be of benefit in thermal design analysis for other payloads. A complete set of data is available from the author.

This contributor to the Project Explorer has enjoyed working with the student experimenters, and the NASA employees associated with the project, and the sponsors: The Alabama Section of the AIAA and the Alabama Space and Rocket Center. I am looking forward to participating in future experiments. Please address any comments to me at the above address.

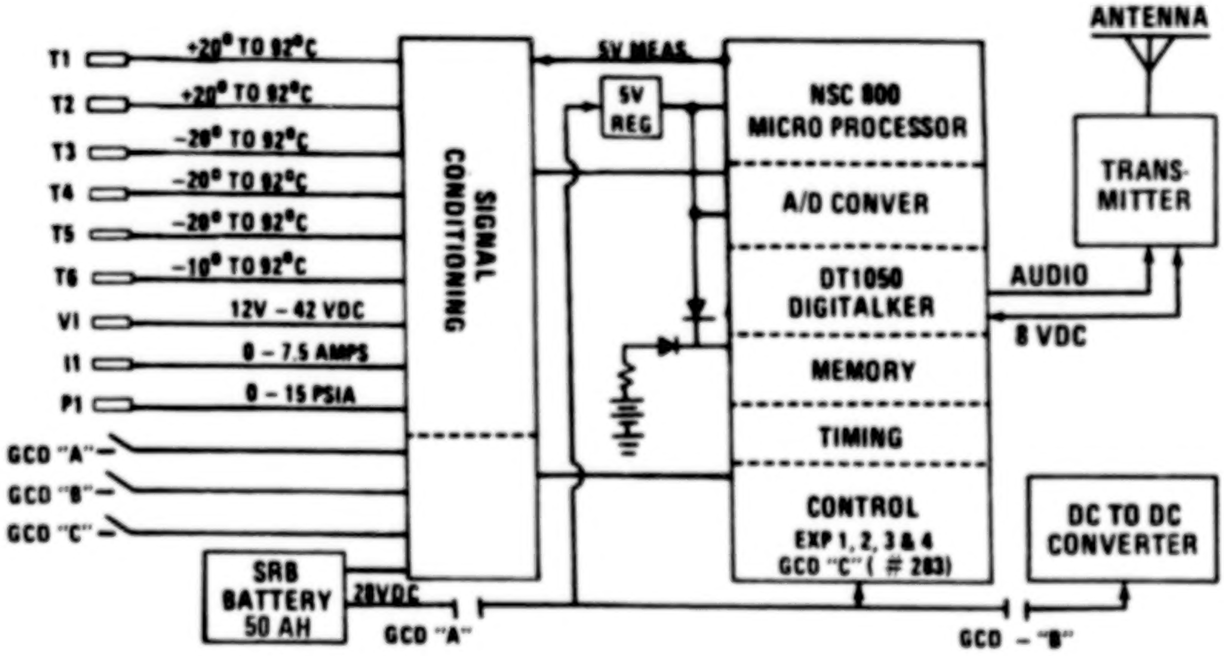

FIGURE 1. MARSHALL AMATEUR RADIO CLUB EXPERIMENT DATA SYSTEM

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GAS 007                                                      V E 1 S S X P A
MISSION                                                      T 2 O W W M T D
TIME      T1    T2    T3    T4    T5    T6    V1     I1   P1   L 3 T C B T L C

 0:00   20.0  20.0   4.7   5.6   4.7   6.2  29.3   .12  14.1   0 0 0 1 1 0 0 0
 0:10   20.0  20.0   5.9   5.4   5.4   6.6  30.8   .65  14.1   0 0 0 1 1 0 0 0
 0:20   20.0  20.0   9.7   5.1   5.4   6.6  31.0   .62  14.1   0 0 0 1 0 0 0 0
 0:30   20.0  20.0  12.2   5.1   5.4   6.4  31.1   .65  14.1   0 0 0 1 0 0 0 0
 0:40   20.0  20.0  13.3   4.9   5.4   6.2  31.1   .65  14.1   0 0 0 1 0 0 0 0
 0:50   20.0  20.0  14.5   4.7   5.1   6.2  31.1   .62  14.1   0 0 0 1 0 0 0 0
 1:00   20.0 ~~52.4~~ 15.4   4.4   5.1   6.0  31.1   .62  14.1   0 0 0 1 0 0 0 0
 1:10   20.0  20.0  15.7   4.2   4.9   5.8  32.2   .47  14.1   0 0 0 1 0 0 0 0
 1:20   20.0  20.0  16.0   4.2   4.7   5.8  31.1   .62  14.0   0 0 0 1 0 0 0 0
 1:30   20.0  20.0  16.3   3.9   4.7   5.8  31.1   .68  14.1   0 0 0 1 0 0 0 0
 1:40   20.0  20.0  16.6   3.9   4.2   5.4  31.1   .62 ~~10.1~~   0 0 0 1 0 0 0 0
 1:50 ~~24.5~~ ~~90.7~~ 16.6   3.7   4.2   5.2  31.0   .62  14.0   0 0 0 1 0 0 0 0
 2:00   20.0  20.0  16.9   3.7   3.9   5.0  31.1   .62  14.0   0 0 0 1 0 0 0 0
 2:10   20.0  20.0  16.9   3.5~~-20.2~~ ~~53.2~~ 31.1   .62  14.0   0 0 0 1 0 0 0 0
 2:20   20.0  20.0  16.9   3.2   3.5   4.8  31.1   .65  14.0   0 0 0 1 0 0 0 0
 2:30   20.0  20.0  16.9   3.0   3.2   4.5  31.1   .62  13.9   0 0 0 1 0 0 0 0
 2:40   20.0  20.0  16.9   2.7   3.0   4.5  31.1   .62  14.0   0 0 0 1 0 0 0 0
 2:50   20.0  20.0  16.9   2.5   2.7   4.1  31.1   .62  13.9   0 0 0 1 0 0 0 0
 3:00   20.0  20.0  16.6   2.5   2.5   3.9  31.1   .62  13.9   0 0 0 1 0 0 0 0
 3:10   20.0  20.0  16.6   2.3   2.5   3.9  31.1   .62  13.9   0 0 0 1 0 0 0 0
 3:20   20.0  20.0  16.6   2.0   2.0   3.5  31.1   .65  13.9   0 0 0 1 0 0 0 0
 3:30   20.0  20.0  16.3   1.8   1.8   3.5  31.1   .62  13.9   0 0 0 1 0 0 0 0
 3:40   20.0  20.0  16.3   1.6   1.8   3.3  31.1   .62  13.9   0 0 0 1 0 0 0 0
 3:50   20.0  20.0  16.0   1.3   1.6   3.1  32.0   .47  13.9   0 0 0 1 0 0 0 0
 4:00   20.0  20.0  16.0   1.1   1.3   2.9  31.1   .65  13.9   0 0 0 1 0 0 0 0
```

FIGURE 2A. GAS007 MEMORY DUMP--FIRST TRANSMISSION CYCLE.

```
20:00   20.0  20.0   6.9-11.7  -9.5  -9.8  31.0   .06  13.4   0 0 0 1 0 0 0 0
20:10   20.0  20.0   7.1-11.2  -8.2  -9.8  30.0  1.03  13.5   0 0 0 1 0 0 0 0
20:20   20.0  20.0   7.1-10.8  -7.4  -9.8  30.3  1.03  13.5   0 0 0 0 0 0 0 0
20:30   20.0  20.0   7.4-10.6  -6.5  -9.8  30.3  1.03  13.5   0 0 0 0 0 0 0 0
20:40   20.0  20.0   7.4-10.2  -5.8  -9.8  29.3  3.06  13.5   0 0 0 0 0 0 0 0
20:50   20.0  20.0   7.4  -9.7  -5.4  -9.8  29.4  3.06  13.5   0 0 0 0 0 0 0 0
21:00 ~~48.3~~ ~~28.6~~  7.4  -9.5  -4.7  -9.8  29.4  3.06  13.6   0 0 0 0 0 0 0 0
21:10   20.0  24.0   7.6  -9.1  -4.1  -9.3 ~~41.3~~ 3.71  13.6   0 0 0 0 0 0 0 0
21:20   20.0  31.3   7.9  -8.6  -3.4  -8.9  30.6  1.03  13.6   0 0 0 0 0 0 0 0
21:30   20.0  36.0   8.2  -8.2  -2.3  -8.4  30.3  1.06  13.7   0 0 0 0 0 0 0 0
21:40   20.0  37.3   8.4  -7.8  -1.6  -8.2  30.6  1.06  13.7   0 0 0 0 0 0 0 0
21:50   20.0  32.8   8.9  -7.1  -1.0  -8.0  30.6  1.03  13.7   0 0 0 0 0 0 0 0
22:00   20.0  27.1   9.2  -6.5   -.5  -7.7  30.6  1.03  13.7   0 0 0 0 0 0 0 0
22:10   20.0  21.9   9.4  -6.3    .4  -7.5  30.7  1.06  13.8   0 1 0 0 0 0 0 0
22:20   20.0 ~~52.4~~ 10.0  -5.6    .6  -7.5  30.6  1.03  13.8   0 0 0 0 0 0 0 0
22:30   20.0  20.0  10.5  -5.2   1.1  -7.1 ~~39.0~~  ~~.00~~ ~~14.9~~   0 0 0 0 0 0 0 0
22:40   20.0  20.0  10.8  -4.7   1.1  -6.8  30.6  1.03  13.8   0 0 0 0 0 0 0 0
22:50   20.0  20.0  11.0  -4.3   1.3  -6.8  30.6  1.03  13.8   0 0 0 0 0 0 0 0
23:00   20.0  20.0  11.6  -3.6   1.3  -6.6  30.6  1.06  13.8   0 0 0 0 0 0 0 0
```

FIGURE 2B. SECOND TRANSMISSION CYCLE.

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GAS 007										V	E	1	S	S	X	P	A
MISSION										T	2	O	W	W	M	T	D
TIME	T1	T2	T3	T4	T5	T6	V1	I1	P1	L	3	T	C	B	T	L	C
42:50	20.0	20.0	8.2	-8.6	-9.5	-7.3	31.1	.09	13.4	0	0	0	0	0	0	0	0
43:00	20.0	20.0	7.9	-8.9	-8.4	-7.3	30.7	1.03	13.4	0	0	0	1	0	0	0	0
43:10	20.0	20.0	7.6	-9.1	-8.0	-7.3	30.6	1.06	13.4	0	1	0	1	0	0	0	0
43:20	20.0	20.0	7.4	-9.1	-7.8	-7.1	29.4	3.09	13.4	0	0	0	1	0	0	0	0
43:30	20.0	20.0	6.9	-9.3	-7.6	-6.6	29.4	3.06	13.4	0	0	0	1	0	0	0	0
43:40	~~25.3~~	~~95.4~~	6.6	-9.5	-7.4	-6.4	29.4	3.06	13.4	0	0	0	1	0	0	0	0
43:50	20.0	20.0	6.6	-9.5	-6.9	-6.2	~~33.1~~	~~7.06~~	~~11.7~~	0	~~1~~	0	~~0~~	0	0	~~1~~	~~1~~
44:00	20.0	20.0	6.6	09.5	-6.5	-6.2	29.7	3.09	13.5	0	0	0	1	0	0	0	0
44:10	20.0	20.0	~~3.5~~	~~-14.7~~	-6.1	-6.2	30.7	1.03	13.5	0	0	0	1	0	0	0	0
44:20	~~46.5~~	~~34.8~~	6.4	~~27.6~~	-5.6	-6.2	30.7	1.03	13.5	0	0	0	1	0	0	0	0
44:30	20.0	20.0	6.9	-6.5	-5.4	-6.2	30.8	1.03	13.5	0	0	0	1	0	0	0	0
44:40	20.0	20.0	5.9	-6.1	-5.0	-6.2	30.7	1.03	13.5	0	0	0	1	0	0	0	0
44:50	20.0	20.0	7.1	-6.1	~~2.5~~	~~3.3~~	30.7	1.03	13.5	0	0	0	1	0	0	0	0
45:00	20.0	20.0	7.4	-5.8	-4.3	-6.4	30.7	1.06	13.5	0	0	0	1	0	0	0	0
45:10	20.0	20.0	7.6	-5.8	-4.5	-6.4	30.7	1.03	13.5	0	0	0	1	0	0	0	0
45:20	20.0	20.0	7.6	-5.8	-4.3	-6.4	30.7	1.03	13.5	0	0	0	1	0	0	0	0
45:30	20.0	20.0	7.9	-6.1	-4.1	-6.2	30.7	1.03	13.5	0	0	0	1	0	0	0	0
45:40	20.0	20.0	8.2	-6.3	-3.9	-6.4	30.7	1.06	13.5	0	0	0	1	0	0	0	0
45:50	20.0	20.0	8.4	-6.5	-3.9	-6.4	30.7	1.06	13.5	0	0	0	1	0	0	0	0
46:00	20.0	20.0	8.7	-6.3	-3.6	-6.4	30.6	1.03	13.5	0	0	0	1	0	0	0	0

FIGURE 2C. THIRD TRANSMISSION CYCLE.

79:00	20.0	20.0	5.9	-12.3	-12.1	-9.8	31.1	.09	13.3	0	0	0	1	0	0	0	0
79:10	20.0	20.0	5.9	-12.3	-12.3	-9.8	31.1	.06	13.3	0	1	0	1	0	0	0	0
79:20	20.0	20.0	5.6	-12.3	-12.1	-9.8	31.2	.09	13.3	0	0	0	1	0	0	0	0
79:30	20.0	20.0	5.6	-12.3	-12.3	-9.8	31.2	.09	13.3	0	0	0	1	0	0	0	0
79:40	20.0	20.0	5.6	-12.3	-12.5	-9.8	31.2	.09	13.2	0	0	0	1	0	0	0	0
79:50	20.0	20.0	-15.1	-17.3	-17.3	-9.8	31.4	.06	13.0	0	0	0	1	0	0	0	0
80:00	20.0	20.0	-11.4	-17.3	-17.3	-9.8	31.0	.05	13.1	0	0	0	1	0	0	0	0
80:10	20.0	20.0	-8.9	-17.5	-17.3	-9.8	31.0	.09	13.0	0	0	0	1	0	0	0	0
80:20	20.0	20.0	-6.9	-17.5	-17.5	-9.8	31.0	.09	13.0	0	0	0	1	0	0	0	0
80:30	20.0	20.0	-5.4	-17.5	-17.5	-9.8	31.1	.09	13.1	0	0	0	1	0	0	0	0
80:40	20.0	20.0	-4.7	-17.5	-17.3	-9.8	31.1	.05	13.1	0	0	0	1	0	0	0	0
80:50	20.0	20.0	-3.6	-17.3	-17.3	-9.8	31.1	.12	13.0	0	0	0	1	0	0	0	0

FIGURE 2D. FIRST REACTIVATION--NO TRANSMISSIONS.

92:30	20.0	20.0	5.9	-12.1	-11.9	-9.8	31.1	.09	13.2	0	0	0	1	0	0	0	0
92:40	20.0	20.0	5.9	-12.3	-12.3	-9.8	31.1	.09	13.2	0	0	0	1	0	0	0	0
92:50	20.0	20.0	-15.1	-16.4	-15.5	-9.8	31.0	.65	13.1	0	0	0	1	1	0	0	0
93:00	20.0	20.0	-11.4	-16.4	-15.1	-9.8	31.0	.62	13.1	0	0	0	1	0	0	0	0
93:10	20.0	20.0	-8.6	-16.2	-15.1	-9.8	30.9	.62	13.1	0	0	0	1	0	0	0	0
93:20	20.0	20.0	-6.5	-16.4	-14.9	-9.8	31.0	.62	13.1	0	0	0	1	0	0	0	0
93:30	20.0	20.0	-5.0	-16.4	-14.9	-9.8	31.0	.62	13.1	0	0	0	1	0	0	0	0
93:40	20.0	20.0	-4.1	-16.4	-14.7	-9.8	31.0	.65	13.1	0	0	0	1	0	0	0	0
93:50	20.0	20.0	-3.0	-16.4	-14.5	-9.8	31.0	.62	13.1	0	0	0	1	0	0	0	0
94:00	20.0	20.0	-2.3	-16.4	-14.5	-9.8	30.9	.62	13.1	0	0	0	1	0	0	0	0

FIGURE 2E. SECOND REACTIVATION--FOURTH TRANSMISSION CYCLE.

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CAL POLY SPACE PROJECT

G-279

by

David R. Farley

ABSTRACT

The Cal Poly Space Project is an effort on the part of several highly motivated students to deploy a space canister which will examine the effects of microgravity on electroplating and immiscible metals. The experiments will be controlled and monitored by a specialized triple redundancy system developed to defer the possible electronic errors due to uncontrollable factors such as photons from the sun. With the finalization of the payload design and the near completion of the data control system, the integration phase of the project is anticipated to be completed and the project ready for launching by early 1987. It is hoped that our experiments will lead to new insights in space research and also prove profitable to industry alike.

Introduction

At California Polytechnic State University, San Luis Obispo, we are taught to "Learn by Doing." Our 2.5 cubic foot canister was donated by Robert Mager in hopes that Cal Poly students could gain scientific knowledge and information along with invaluable career experience.

For the past seven years students from a variety of fields have worked and learned collectively to make the Cal Poly Space Project a reality. Among these contributions are many university required senior projects, which ranged from a financial report and budget to stress analysis testing. Since the program is coordinated completely by students, the experience has been uniquely rewarding as well as preparation for entering our respective professions.

Electroplating

In microgravity many things can be done more easily and efficiently. Our electroplating experiment examines the effect of microgravity to produce a more uniform and higher quality plating. We will run sixteen separate cells, each utilizing differing agitation rates and type of plating (nickel or composite). In addition, the cathodes of the cells will have different shapes to determine if odd shapes promote a lesser quality plating. Small electronic components will be nickel plated and bearing steels will be plated with a tungsten carbide composite by the codeposition process. Codeposition involves suspending tungsten carbide particles in the electrolyte that become embedded in the plating to produce a hard, corrosion-resistant surface.

Immiscible Alloys

Our other experiment will produce an alloy from immiscible metals that would be extremely difficult to accomplish on earth. After being melted and combined, the effect of microgravity should allow the metals to solidify without separating. The two furnaces used for the immiscible alloys experiment were designed and built by the Space Payloads Group in exchange for 22 furnace body shells manufactured at Cal Poly. When the samples have returned to earth they will be analyzed by photomicrographs, X-Ray diffraction, and a measurement of the superconducting transition temperature and critical field.

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CAL POLY SPACE PROJECT

FURNACE MOUNT LAYOUT
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ROB KNESTRICK, P.TEMP
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3-6-86.
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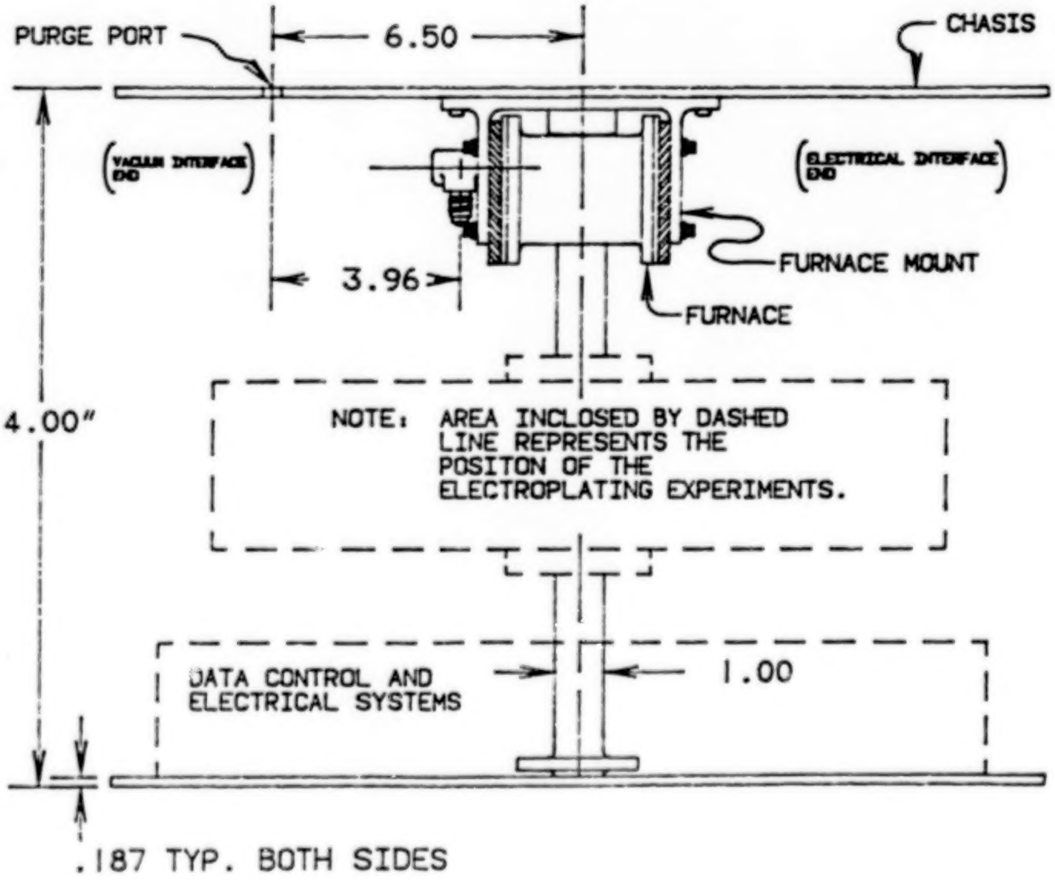

NOTE: AREA INCLOSED BY DASHED LINE REPRESENTS THE POSITON OF THE ELECTROPLATING EXPERIMENTS.

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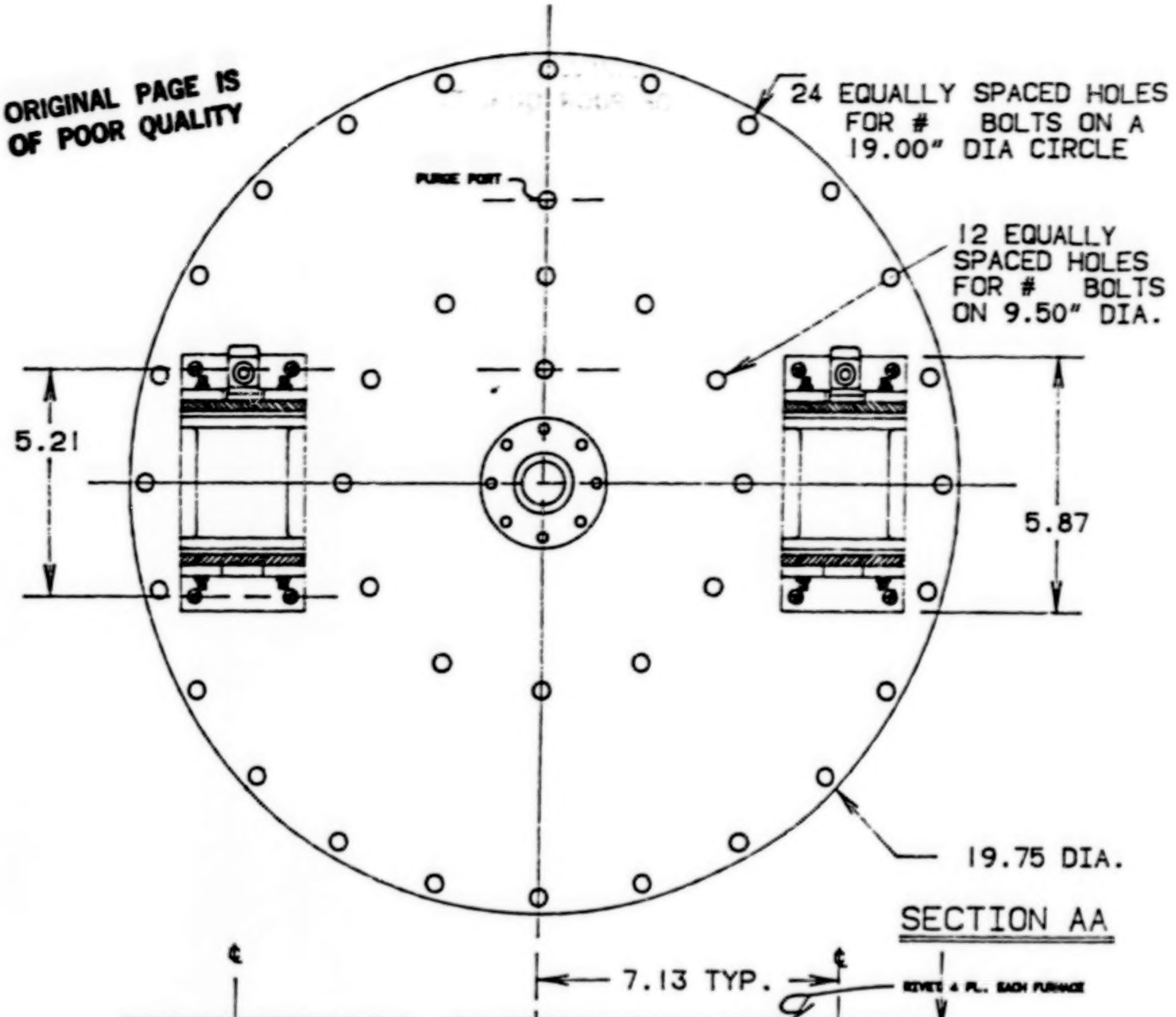

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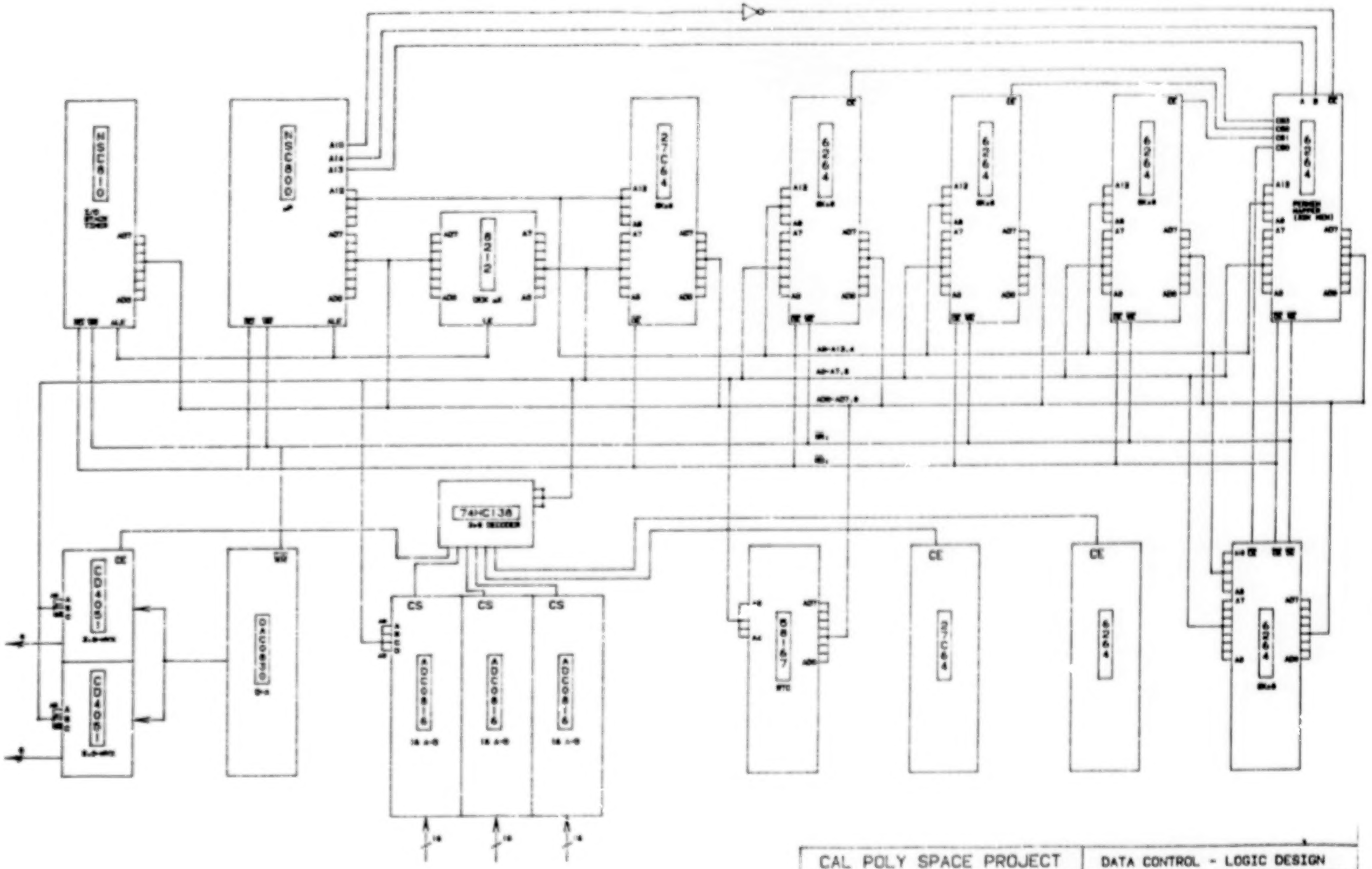

CAL POLY SPACE PROJECT | DATA CONTROL - LOGIC DESIGN
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Data Collection and Control

Reliability is our main concern with the data collection system. We will be using a specialized triple-redundancy approach which should defer any unanticipated hazards. Data collection and control is comprised of a microprocessor with a real time clock, which will count levels of power, temperature, rates and time operations. The system uses an analog to digital converter, a digital to analog converter, EPROM to store the program, and RAM to store the data. A "Watchdog" ROM chip will decide if the primary microprocessor is performing correctly. If the primary microprocessor is inaccurate, then full control of the experiments is transferred to the secondary processor, and finally a third processor would gain control if the second malfunctions. These precautions should provide ample reliability for our experiments.

Chassis

The Aluminum chassis has a modified cantilever structure which has been designed, built, and tested. All experiments and support systems shall be connected to a central vertical pole which will save space as well as keep the components securely in place. Vibrational and stress analyses were performed on an identical test structure. The chassis was found to have a fundamental frequency of 80 Hz.

Conclusion

We will be conducting our test analysis of the entire project as soon as all the components are completed and integrated. By the time the Space Transportation System is again operational, our project shall be ready. A few selected members of our group will transport the project to Kennedy Space Center and also witness the launching of the Space Shuttle. After retrieving the canister, an examination of the products and recorded data will enable us to discover exactly what occured during each experiment.

Possibilities of a future project are already being considered. The experience gained from our first project will be extremely advantageous to us for a more productive and timely second project. As a result of the Cal Poly Space Project, our members feel confident of their abilities and are also prepared for their futures.

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THE GROWTH AND HARVESTING OF ALGAE IN A MICRO-GRAVITY ENVIRONMENT

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G-285

ABSTRACT

Algae growth in a micro-gravity environment is an important factor in supporting man's permanent presence in space. Algae can be used to produce food, oxygen, and pure water in a manned space station. A space station is one example of a situation where a Controlled Ecological Life Support System (CELSS) is imperative. In setting up a CELSS with an engineering approach at the Aerospace department of the University of Colorado, questions concerning algae growth in micro-g have arisen. The Get Away Special (GAS) Fluids Management project is a means through which many questions about the effects of a micro-g environment on the adequacy of growth rates, the viability of micro-organisms, and separation of gasses and solids for harvesting purposes can be answered. In order to be compatible with the GAS tests, the algae must satisfy the following criteria: 1) rapid growth rates 2) sustain viability over long periods of non-growth storage 3) very brief latency from storage to rapid growth. Testing indicates that the overall growth characteristics of Anacystis Nidulans satisfy the specifications of GAS's design constraints. In addition, data acquisition and the method of growth instigation are two specific problems being examined, as they will be encountered in interfacing with the GAS project. Flight testing will be two-fold, measurement of algae growth in micro-g and separation of algae from growth medium in an artificial gravitation field. Post flight results will provide information on algae viability in a micro-g environment as reflected by algal growth rates in space. Other post flight results will provide a basis for evaluating techniques for harvesting algae. The results from the GAS project will greatly assist the continuing effort of developing the CELSS and its applications for space.

ONCE UPON A TIME, IN A GALAXY FAR, FAR AWAY

Single cell plant growth in a micro-gravity environment may become crucial for the eventual long-term human habitation of remote space. Currently large fractions of all payloads used in manned space efforts are used to carry water, oxygen, and food into space. In the future, continually replenishing the supplies of a space station will not be economically feasible because of the length of planned missions and the distances from Earth such missions will involve. For example, the minimum cost to transfer a kilogram(kg) of supplies to geosynchronous orbit is approximately 28,600 dollars. For a ten man crew approximately 7,700 kgs of food and water would need to be supplied every six months. This results in a net cost of 220,000,000 dollars every six months just to replenish the crew's food and water supply. A comparison of such an "open" food system with a 97% "closed" supply system as might be made available through a CELSS indicates that for a crew of twelve, 455,000,000 dollars would be saved over a fifteen year period. For such economic reasons, research is currently being performed in developing a Controlled, or Closed, Ecological Life Support System (CELSS), as an alternative to resupply. It also is clear that very remote missions must depend on regenerative life support because resupply would be almost impossible to achieve in a safe reliable fashion. The CELSS is a bioregenerative system, that supplies food for the crew, recycles oxygen, water, and wastes, and maintains itself as a biologically viable entity. This system is considerably more cost beneficial than a system involving resupply, and is therefore considered crucial to supporting a variety of proposed manned space efforts.

Algae has the characteristics to make it the prime candidate as an integral part of a CELSS. Algae requires low maintenance and small volumes. In addition, it has a high ratio of useful biomass (protein and carbohydrate) to nonuseful biomass and provides necessary conversion of carbon dioxide to oxygen. Energy for these bioconversions can be made directly available from the sun. Limited considerations of the behavior of algae in micro-gravity have been completed. Research of particular interest was performed by Steven Walker of Utah State University, 1980. This research however, deals only with the growth of algae, Chlorella, in a micro-gravity environment and not harvesting. The present paper presents work in progress at the University of Colorado Aerospace Engineering Sciences Department in developing a Get Away Special (GAS) experiment designed to determine the utility of a specific method 1) to ensure rapid algae growth and 2) to achieve effective algae harvesting in a micro-g environment.

The proposed experiment involves two stages. The first stage involves controlled time periods for algal growth both with and without artificial gravity. On orbit data acquisition will be accomplished using pH indicators and turbidity measurements of growth documented photographically through appropriately positioned fiber optic sensing elements. The growth stage will provide information about the viability of lower plants, specifically algae in a space environment where the separation of fluid and gases is absent. The question arises as to whether the oxygen and carbon dioxide behavior will aid or inhibit algae growth. The second stage is a fluids management experiment involving multi-phase medium separations. The three phases to be separated are gases, nutrient solution, and algae. The data received from this part of the experiment will aid in designing a fluids management system with applications for supporting fluid transfers in space, fluid venting and gauging in space as well as a variety of space habitation needs. The main areas of research for this experiment deal with the choice of algae, maintenance of a suitable growth atmosphere, data acquisition, algae storage, growth instigation in orbit, and actual harvesting of algae.

DECISIONS, DECISIONS

In order to conduct both the ground and space facets of a successful experiment several important and limiting constraints must be met. The main experimental related to space tests is time. There are two major difficulties encountered in observing the time guidelines. An approximate three month storage phase occurs while the canister is waiting for lift-off. To assure that the necessary growth rate is obtained during the experiment, no algae growth can occur prior to instigation on orbit. Once on orbit instigation occurs, two hours has been allotted to the complete fluids management experiment, largely because of power limitations. This creates the need for a fast growing strain of algae. Other constraints include the need for correct spectrum lights (twenty-two watts cool white fluorescent) that do not alter the test chamber ambient temperature from 40 ± 2 degrees Celsius. The constraints imposed by the CU Get Away Special project for power and space are 112 watt-hours and approximately ten liters devoted to the total fluids experiment. NASA's safety standards require that the algae and associated media be non-toxic. Each of these constraints required considerable ground testing before an appropriate flight configuration could be finalized.

The first step in ground testing was to identify three strains of algae which appeared to satisfy the constraints of a CELSS. These strains are Anacystis nidulans, Chlorella, and Euglena gracilis. Laboratory testing was done to determine growth rates under a variety of light and nutrient conditions. The pigmentation increments of the growing algae was noted since this would be a critical element in photographically recording growth rates. (See Table I) The testing yielded data that corroborated available data that indicates Anacystis nidulans has the fastest growth rate and the best pigmentation for the data acquisition phase of this GAS experiment. Research indicates that Anacystis nidulans satisfies the NASA constraint that it is non-toxic. (Gorham, 1962)

Table I

Growth Characteristics for Flight Simulations

algae	class	maximum growth rate (k)	simulation growth rate (k)	optimal growth temperature (C)	pigmentation and sedimentation
Anacystis nidulans	blue-green	3.55(1)	0.98	41° C	vibrant blue-green color no sedimentation
Chlorella	green	0.56(2)	0.15	25° C	light green sedimentation
Euglena Gracilis	euglenoid	—	—	—	no visible growth no further research

(1) reference Kratz and Myers, 1955

(2) reference Fogg, 1965

After selecting Anacystis nidulans as the test algae, more detailed experiments were done assessing altered growth media, carbon sources, heat and light. These variables were evaluated with regard to growth rates and latencies to achieve maximal growth rates. Five different growth media were researched, four of which were mixed in the laboratory, and one of which was purchased premixed. The premixed medium, Alga-Gro Freshwater medium, along with Kratz and Myers medium "C", and Popcock's medium all supported robust growth. The other two mediums, Grand Island Biological cell culture medium, and Beijerinck's medium did not support adequate growth in the laboratory test conditions. Currently, Alga-Gro and Kratz and Myers medium "C" are the two media being considered for use during flight testing. Kratz and Myers medium "C" is slightly favored since, unlike Alga-Gro, the exact chemical composition is known and can easily be altered to fit any changing or unanticipated needs of the experiment. (See Table II)

Table II
Medium C

salt	concentration, g/l
$MgSO_47H_2O$	0.25
K_2HPO_4	1.00
$Ca(NO_3)_24H_2O$	0.025
KNO_3	1.00
Na Citrate $2H_2O$	0.165
$Fe_2(SO_4)6H_2O$	0.004
A_5Microelements[a]	1.0ml

[a] A_5Microelements stock solution : H_3BO_3. 2.86g/l: $MnCl_24H_2O$. 1.81g/l: $ZnSO_4H_2O$. 0.222g/l: MoO_3(85%). 0.0177g/l: $CuSO_45H_2O$. 0.079g/l

Growth Medium
Adapted from Kratz and Myers. 1955

Not all of the growth medium recipes contained a separate enriched source of carbon that is a necessity for the rapid growth of blue-green algae. Several methods of supplementing a growth medium lacking a carbon source were examined. One method was to add glucose, $C_6H_{12}O_6$, to the mediums that did not contain any separate carbon source. This method did not support growth. Glucose, a six-sided sugar, is apparently too large to diffuse across the algal membrane and algae are primitive cells that do not have a glucose transport mechanism. The second attempt was to add biotin, $C_{10}H_{16}O_3N_2S$ to the medium. Biotin is a colorless crystalline growth vitamin of the vitamin B complex. This method did not result in any recordable growth by the algae either. The final method, suggested in an article by Kratz and Myers 1955, was to bubble CO_2 through the medium. Limited bubbling was done on their medium "C". The resulting medium supported growth well; it has a growth rate comparable to Algal-Gro under the same heat-light conditions. The bubbling of the CO_2 was accomplished by containing dry ice in a stopped flask with a tube connecting it to a flask of growth medium, for approximately five minutes. To achieve maximum growth rates for Anacystis nidulans, constant bubbling of air containing 4% CO_2 through the growth chamber is recommended by Kratz and Myers. Constant bubbling is not feasible for implementation in this experiment due to volume and power constraints. Rather, the growth medium would have to be saturated with carbon dioxide prior to lift off and the algae would be inoculated into the growth medium while on orbit.

The optimal temperature for growth of Anacystis nidulans is 41 degrees Celsius. For test simulation purposes, Anacystis nidulans was grown at room temperature and in an incubator set at 40 degrees Celsius. Rate of growth can be expressed in terms of a specific growth rate, k, defined by the growth equation $\log_{10} N/N_0 = kt$. The variable k is expressed in $\log_{10}$ units per day: when $k = 0.301$ the population doubling time is one day. For Anacystis nidulans, Kratz and Myers report $k = 0.87$ for growth at 25 degrees Celsius and $k = 3.55$ at 41 degrees Celsius. Tests with simulated GAS experiment conditions, using Anacystis nidulans as the test algae, resulted in $k = 0.120$ to $k = 0.181$ at a growth temperature of 25 degrees Celsius and $k = 0.380$ to $k = 0.903$ at a temperature of 40 degrees Celsius. Kratz and Myers used optimal growth conditions, while testing at the University of Colorado's biolab was conducted under conditions similar to flight. During flight, a thermal blanket will be wrapped around the storage container in which the algae growth will occur. This insulation coupled with lighting control should permit some degree of temperature regulation during on orbit algae growth. The thermal blanket and light controls are expected to help maintain a constant temperature of 40 ± 2 degrees Celsius.

The sensitivity of the algae to light levels was also considered. No growth is recorded when the algae does not receive any light. Cool white fluorescent light is recommended by the Carolina Biological laboratories because of the spectrum of light emitted. Accordingly, twenty-two watt cool white fluorescent lighting was used in the laboratory and was found to sustain rapid algae growth. During flight, such a twenty-two watt cool white fluorescent light tube will be used adjacent to the growth chamber to provide the light necessary for growth. As noted above, lighting cycles may have to be modified to support appropriate temperatures in the growth chamber.

BEHIND THE SCENES; THE DIRTY WORK

Growth rates were obtained by taking population measurements over time. These growth measurements were collected using a drying and weighing system. To acquire a data point, 100 milliliters(mls) of algae in its growth solution were spun down in 15 ml test tubes in a centrifuge at roughly 1300g. The supernatant was taken out of the tubes leaving an algae rich solution. The algae rich solution was then aspirated through 0.22 micron Millipore filters. The Millipore filters were previously weighed and saturated with 0.15 M NaCl solution to prime them for the filtration process. The algae solution was aspirated two times through the filter. The filter was then placed on a glass dish for twenty hours in an oven set at 50 degrees Celsius. After the drying time had elapsed, the filter was then reweighed. This is a simple effective way of determining the dry weight of a sample of algae. And, from such dry weights the growth rate of the algae can be determined. (See Figure III)

Since the above procedure does not lend itself to on orbit measures of algae growth, alternative schemes were assessed. The pH changes associated with growth were a particularly attractive alternative since measurements could be recorded in a number of different ways. For testing, bromthymol blue and phenol red were the two chemical pH indicators that were added to the algae solutions. Bromthymol blue has a pH range of 6.0 to 7.6, whereas phenol red has a range of 6.8 to 8.4. The color ranges were from yellow to deep blue or to dark red, respectively. To establish the utility of the two pH indicators, a ten ml sample of active algae growth solution containing the indicator was collected daily. The samples were stored in a refrigerator in the dark. Photos were then taken to provide visual indications of growth that can be later calibrated. This also tested the algae's viability when mixed with an indicator. During actual flight, an indicator with a large color range in a small pH change will be used, as the growth time is restricted to two hours. A change in pH indicates a change in acidity associated with growth and utilization of the carbon dioxide. The formula that relates pH to H+ ions is $[H+] = 10^{-(ph)}$. A change in pH of an algal solution indicates growth. (See Figure IV)

WHEN SHE FLIES

As stated previously, the time constraints of the GAS Experiment present a unique problem. The algae will be stored for the approximate three months prior to launch with neither heat nor light. During this phase, no growth may occur. Lyophilization, freeze drying, was one option considered for storage. It was rejected due to an accompanying lag time needed before growth occurred. Another approach considered is storing the algae in a medium with vital growth components missing. The question arises as to whether or not a medium that is deficient in vital ingredients will support life for three months. A method of storage being examined currently is storage of the algae in a medium that brings the algae to asymptotic growth, or in a stationary phase. Algal solutions that are asymptotic are being subjected to several months of tests in an environment lacking illumination or heat. Research has been performed to find the algae concentrations at which the growth rate is asymptotic. This information coupled with the mode of storage will determine an optimal initial population for the experiment.

Once the on flight experiment begins, rapid growth of the algae is imperative. Little growth lag time may occur during the two hours of data acquisition. It is envisioned that instigation of algae growth will be accomplished using a piston action to puncture plastic films which will allow the mixing of two separate mediums. One medium will contain the asymptotic algae, the other will contain the rapid growth instigating nutrients. Data acquisition will then occur using pH indicators, fiber optics, and photographs taken at specific time intervals.

The second stage of the experiment involves separation of the algae from gasses and growth medium. This will provide useful information for recovering solids suspended in fluids, specifically, algae harvesting. Separation will be achieved through centrifugation and accompanying fluid density gradients. A clumping agent may be added to aid in density stratification of the three phases. Data acquisition during this stage will also be accomplished using time interval photography.

APODOSIS

The GAS Project is limited; the strict constraints do not allow an ideal testing situation and there are many potential failure points. Loss of power, component breakage during launch, misalignment of data acquisition equipment, or loss of thermal control, would all be catastrophically detrimental to experiment success. In most operational scenarios, even those including such a detrimental event, valuable data will be generated. For example, if camera failure occurs, the examination of the algae remaining in the centrifuge, storage container, and connecting tubing, will reveal minimal data on growth. In the case of a total or partial loss of thermal control, the growth of Anacystis nidulans will be diminished, possibly below the level of recordable growth. Lighting failure would be more catastrophic than thermal failure. Ground testing indicates that very minimal growth occurs in situation with no illumination. In addition, visual methods of data acquisition of growth and separation would be rendered useless. Except in the extreme cases, however, these failures would only limit and minimize, not eliminate useful data.

Experiment failures could also occur due to testing in a micro-g environment. The possible reluctance of gases (CO_2, O_2) to separate from the medium would affect the pH, and in turn make the calibration of data difficult. Ground testing will provide information about latencies to growth maxima. This information may become irrelevant in a micro-g growth environment, as latencies to growth maxima may change. These events should not be viewed as providing useless information, as important data about the growth of algae in a micro-g environment will still be retrieved.

The CU GAS experiment is expected to fly as soon as the Shuttle Program becomes operational. Decisions have been made concerning the algae. Anacystis nidulans grown with a temperature of 40°C and twenty-two watts cool white fluorescent lighting. On orbit data acquisition will be accomplished using pH indicators and fiber optics. Much research still needs to be performed in order to make the GAS project flight ready. Future testing will include: triggering rapid growth of algal solutions currently being stored in a stationary growth phase, continued pH calibration for data acquisition, experimentation in promoting faster algal growth, and centrifugation at speeds comparable to speeds encountered during in-flight experimentation to examine growth rates and separation. Future, as well as completed ground testing not only aids in the preparation of the CU GAS Project, but also provides valuable background information for the future development of a CELSS.

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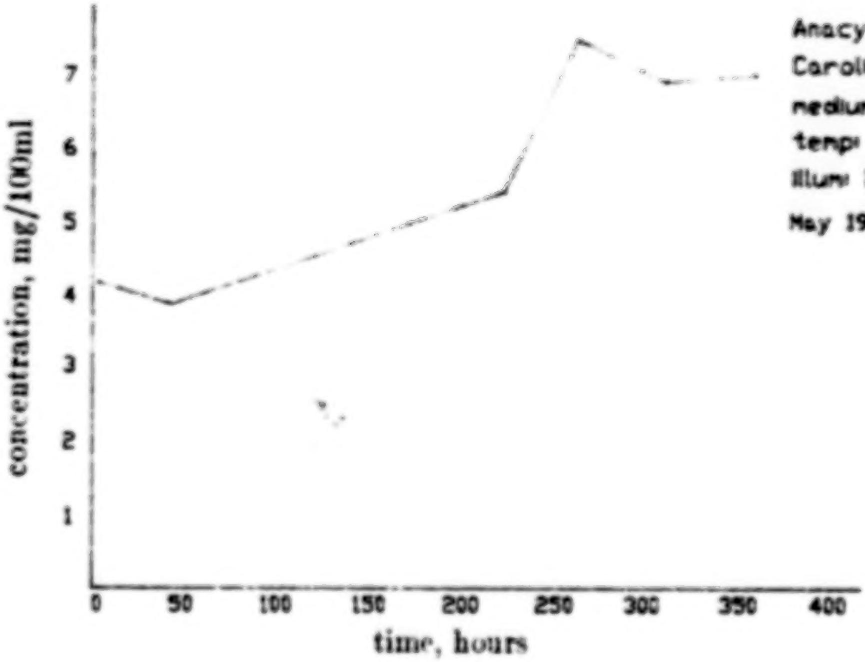
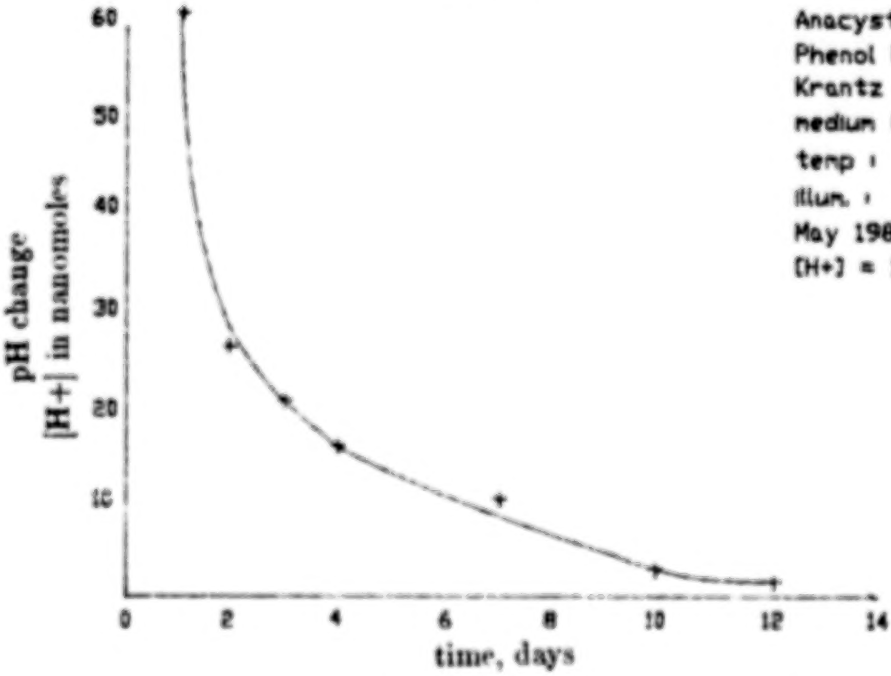
Figure III



Anacystis Nidulans
Carolina Biological
medium: 2x normal
temp: 41 c
Illum: 22 w
May 1986

Growth Curve

Figure IV



Anacystis Nidulans
Phenol Red Indicator
Krantz and Myers (1955)
medium C
temp : 41 c
Illum. : 22 w
May 1986
$[H+] = 10^{-(Ph)}$

pH Change with Days of Growth

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TO CATCH A COMET II
Technical Update on CAN DO

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Abstract

Since the presentation of "To Catch A Comet" was given at the last G.A.S. Symposium, many events have impacted the CAN-DO Comet Halley program. This paper summarizes the changes to the payload and its mission, including improvements in camera control and CAN-DO's participation in the "Halley Armada".

The System

The Astro-1 / CAN-DO payload is configured for widefield astrophotography in the visible and ultraviolet spectrum, under active astronaut control. Sealed with one atmosphere of dry nitrogen in a five cubic foot canister, four Nikon F-3 35 mm cameras with 250 exposure film backs photograph through a fused silica window protected by a motorized door assembly. Four lenses were chosen for the study of Comet Halley on STS-61E in support of the Astro-1 mission, a 200 mm / F2 ED, a 105 mm / F2.5, a 105 mm / F4.5 Ultraviolet Nikkor with a Schott UG-11 3000-3300 Å Ultraviolet filter, and a 58 mm / F1.2 . Kodak EES P800/1600 color film was selected based on extensive film tests for visible light coverage and Tri-X Pan 400 for its UV sensitivity.

Operation

All cameras would be fired simultaneously under GCD relay control (Fig-1). At about 30 hours M.E.T., GCD-B energizes the environmental systems, the camera control systems, and opens the enabled MDA. At the beginning of each window, when an object of interest is aligned with the shuttle's Z-axis, toggling GCD-C starts a five photograph series of varying exposure lengths. Each camera is controlled by its own

C-3

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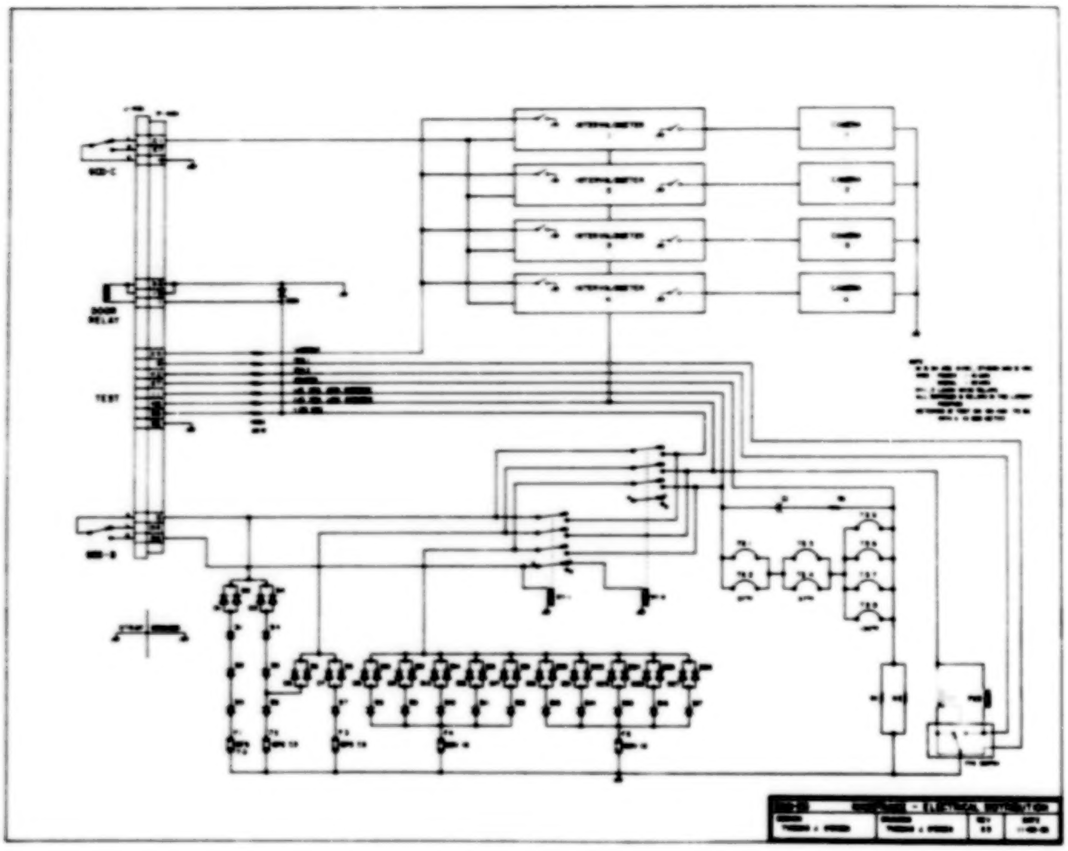

Fig-1

intervalometer which can be programmed for up to eight exposures selecting from ten exposure lengths before it resets to await the next "fire" command.

In an effort to extend CAN-DO's operational life to more fully support Astro-1, further testing was performed in cooperation with the Langley Research Center and the Goddard Space Flight Center. A full mission profile was "flown" in a thermal chamber to identify heat loss paths and improve on insulation since heat loss was the prime mission limiting factor. Additional G-10 thermal barriers were added to conductive heat paths and a conformal jacket of Rubatex EVA closed-cell foam insulated the payload interior. Testing now indicated CAN-DO's mission life should exceed 150 hours. While new thermal, EMI, shake and vibration tests were being conducted, a new window was being manufactured by Muffoletto Optical Co. in Baltimore, Md. under the supervision of Goddard with the support of the Astro-1 project. This new optically clear 0.92 inch fused silica window would allow a full one atmosphere Nitrogen seal while allowing both visible and ultraviolet photography. Delivery was scheduled for January 2nd which allowed time for flight certification testing to meet CAN-DO's mid-January integration at the Goddard Space Flight Center. After further testing and integration, CAN-DO was shipped to the Cape for its January 26th date in the OPF with Columbia.

With news of the Challenger disaster and the hold placed on further operations, consideration was given to operating the payload cameras piggy-backed on a tracking telescope similar to the ones used for the film tests. During this time, it was learned that the N.A.S.A. / Ames Research Center Medium Altitude Division would deploy their two airborne observatory aircraft to the Southern Hemisphere in March and April to study Comet Halley, several IRAS objects, and others unavailable for study further north. After technical proposals, numerous drawings, and many test results were exchanged with the Ames staff, Astro-1 / CAN-DO joined the Kuiper on its Southern Deployment to Christchurch, New Zealand.

The Kuiper

The Ames Research Center - Gerard P. Kuiper Airborne Observatory is a modified Lockheed L-300 Starlifter (Air Force C-141A) with a 36 inch infared telescope mounted in a cavity forward of the wings. This telescope and cavity (Fig-2) is open to the outside world for unobstructed infared astronomical observations.

The telescope itself floats on an 18 micron film of air around a 16 inch Invar air bearing mounted on four pneumatic vibration isolators. Rotating on its air bearing, the telescope can be mechanically elevated from 35° to 75° above horizontal. During an observation leg which is plotted to set the telescope azimuth, the autopilot maintains a pointing window within the ±2° cone-of-correction of the ADAMS tracking computer, even in moderate turbulence. Under normal conditions, pitch and yaw can be maintained within a few tenths of a degree. Pointing is referenced to azimuth, elevation, and line-of-sight gas bearing gyroscopes.

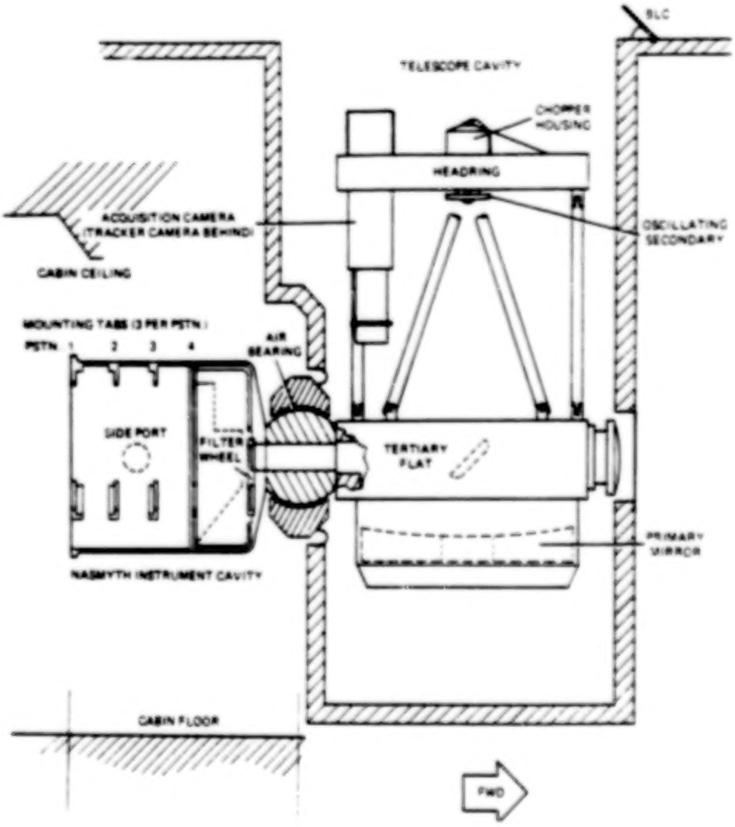

Fig-2

To begin an observation, the desired star field is located on the widefield acquisition television camera. After the star field is identified and centered, the narrowfield tracking television camera is locked on a reference target which provides tracking information to the computer controlled tracking servo system.

The System

Since the KAO would be studying Comet Halley on several flights during its stay in New Zealand, it provided the ideal tracking platform, well above most atmospheric water vapor and possibly with enough ultraviolet light for photography for the Astro-1 / CAN-DO camera system. The drawings supplied by Ames showed just enough room to mount two Nikon F-3's without the 250 exposure film backs, on the headring of the telescope (Fig-3). This location, however, introduced several problems. Instead of an internal canister ambient temperature of 0°C at one atmosphere, the cameras would be exposed to a 6 to 8 hour pre-flight pre-cool cycle at -50°C and a mission operating temperature of between -40 and -55°C at only 0.15 atmosphere. In addition, mounting the cameras on the face of the headring would expose them to some turbulence.

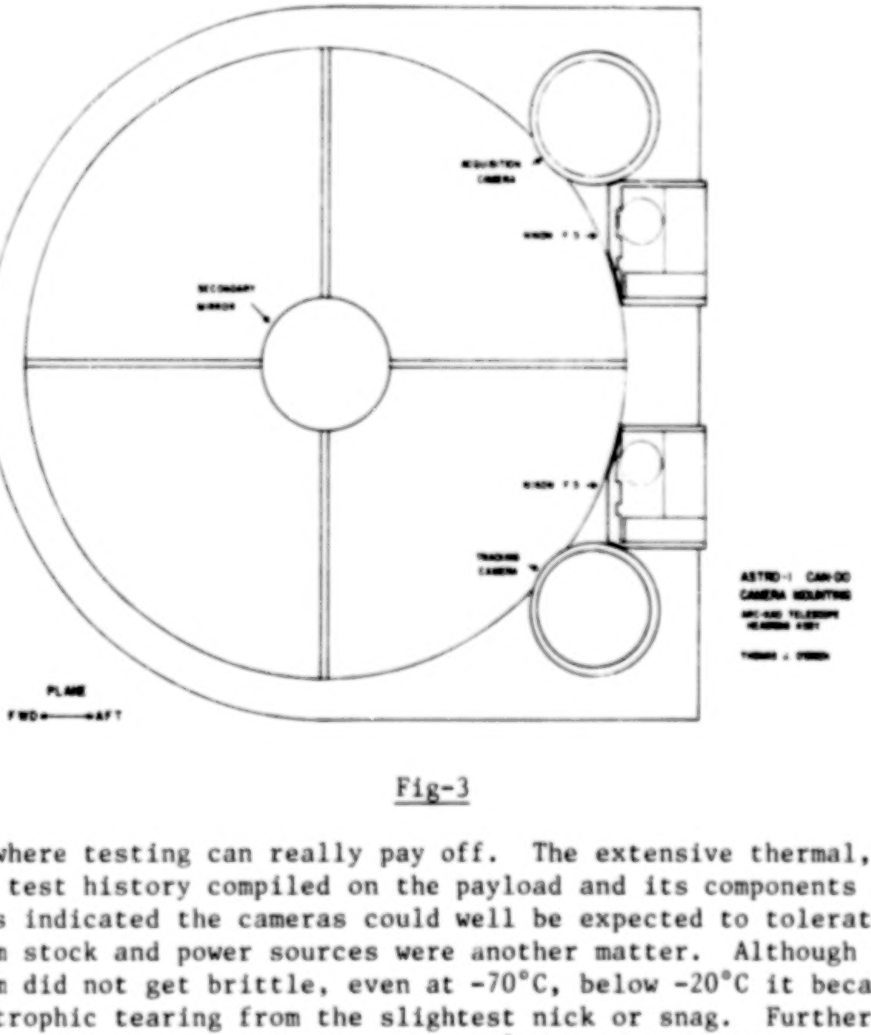

Fig-3

This is where testing can really pay off. The extensive thermal, EMI, shock and vibration test history compiled on the payload and its components as part of the design process indicated the cameras could well be expected to tolerate these conditions. Film stock and power sources were another matter. Although testing had shown the film did not get brittle, even at -70°C, below -20°C it became susceptable to catastrophic tearing from the slightest nick or snag. Further, below 0°C, battery efficiency fell off rapidly and at -50°C it was terrible.

Powering the cameras remotely from inside the KAO solved the power problem but but film handling looked insurmountable. The threat of interference with the sensitive infared detectors in the telescope ruled out strip heaters and the tight space constraint on the camera mounting assemblies didn't allow for insulation. After considering the alternatives, it was decided that a "soft" start for film advance would do the trick. To seperately "ramp-up" each film advance motor would add four additional wires to the four shutter control and four camera power wires. In spite of the quiet performance of the F-3 on the EMI tests, 125 feet of a 12 conductor cable seemed to be tempting fate.

Now the Nikon F-3 shutter interlock allows a unique solution to this problem. During one of the many tests on the F-3, it was found that when the shutter is permanently enabled, if the power is removed and reapplied, the shutter will open and remain open until the power is removed, closing it. When power is reapplied, the film will advance and reset the shutter to await the next off/on cycle. By monitoring the supply current, the operating mode, film condition, and electronic performance can be followed.

In the control system (Fig-4) S-102/S-104 can control each camera individually, while S-103 or S-105 control both cameras simultaneously. The control signal from a switch or external source determines the exposure length by either start/stop pulses of less than 1.5 seconds each or a single pulse the length of the desired exposure.

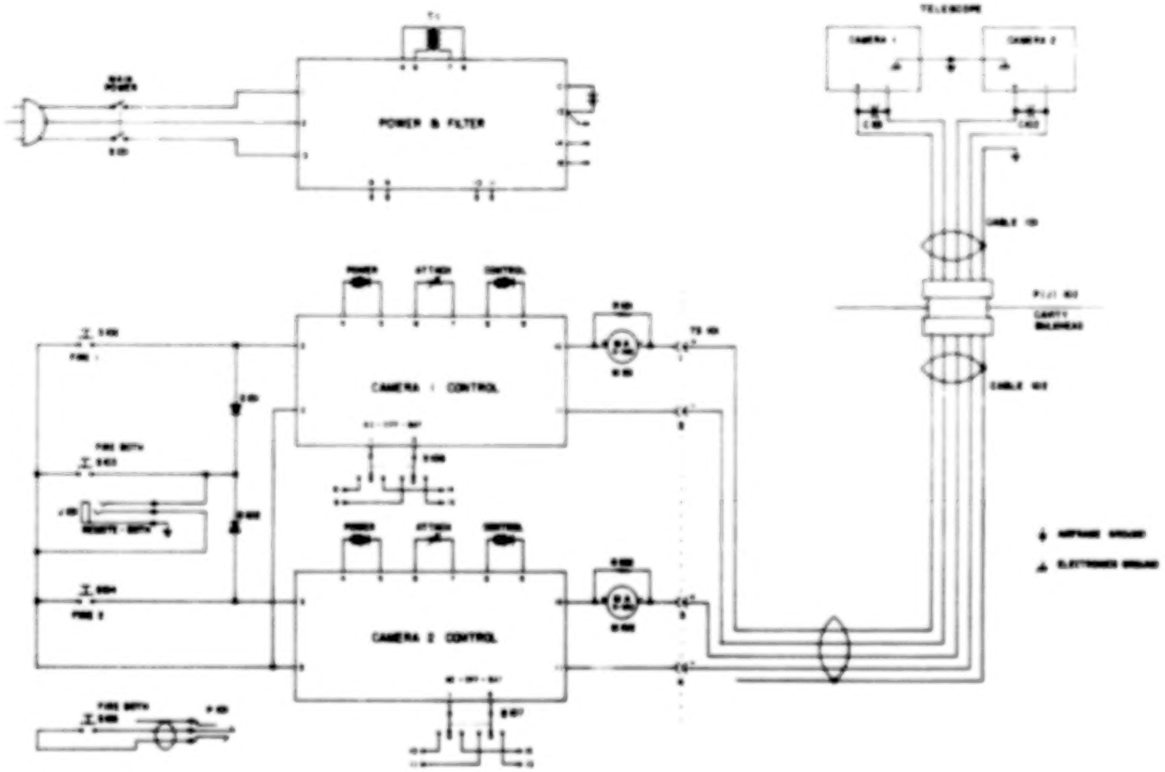

Fig-4

The monostable multivibrator U2A/B (Fig-5) delivers a 1.5 second pulse for every positive or negative transition of the control input (U2 1-10). If the transitions are seperated by more that 1.5 seconds, the first initiates the next camera function (ie: shutter open) and the second starts the following function (close shutter, advance film). If, however, the second transition occurs before the end of the multivibrator 1.5 second output, it will be ignored and a third

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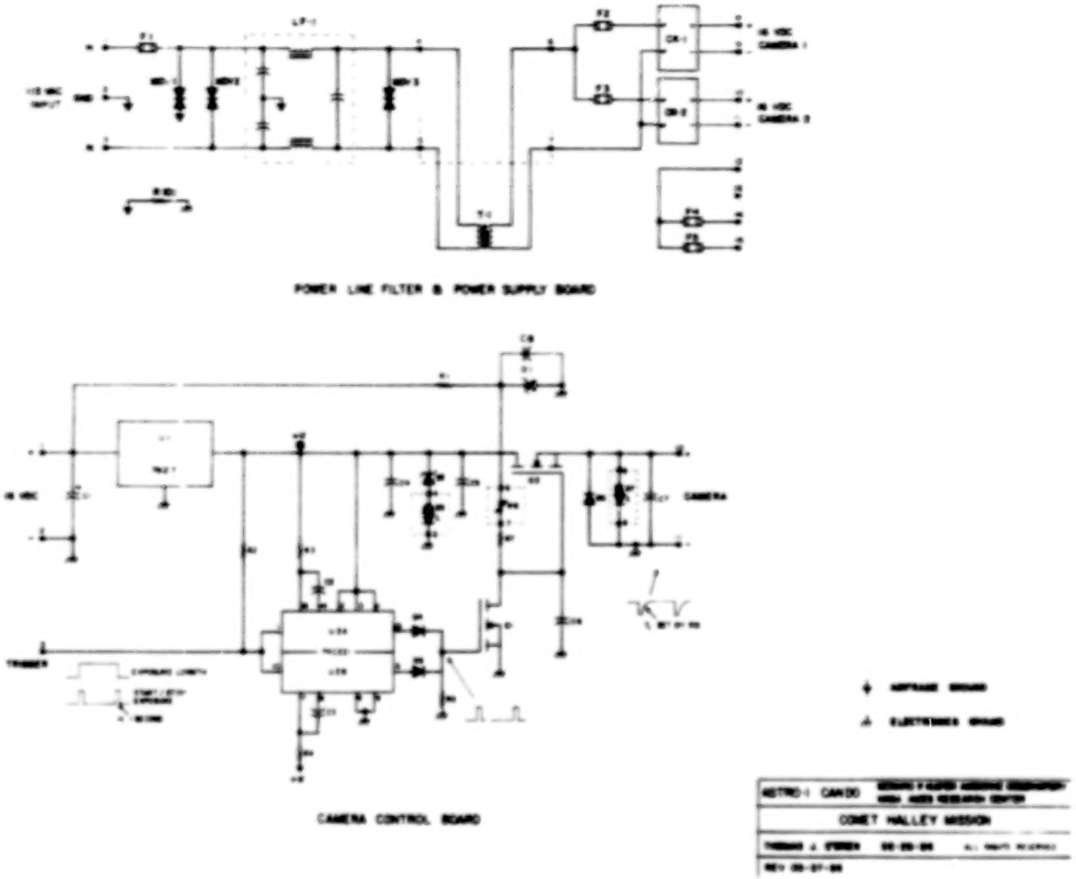

Fig-5

transition will be needed to initiate the next function. The multivibrator outputs are applied to the gate of FET Q1 via D4/D5. On command of U2, Q1 saturates and discharges C6. After 1.5 seconds, C6 is released by Q1 and begins to charge through the R/C time constant formed with R6/R7. This "soft" exponential rise in voltage controls the conduction of Q2, the series pass control FET for the cameras operating voltage.

Although primary power was intended to be drawn from the KAO's 115 VAC/60 Hz supply, the possibility of a ground loop, noise on the line, or availability in our location in the plane had to be considered. As an emergency backup, an internal 18 VDC Duracell Alkaline battery stack from the shuttle payload was included for independent "floating" operation.

Mounting the Cameras

An extensive test history with a three point mounting system on the F-3 led to a design for mounting the cameras that gave easy access to the film and lenses between flights. These brackets (Fig-6) were mounted on the face of the telescope headring (Fig-3) by an aluminum "Y" that was bolted to the bracket through existing three inch holes inboard of the tracking and acquisition cameras.

Flights

The first flight on April 6th yielded spectacular results and the cameras performed flawlessly. To verify the film tests, it was decided that on this flight,

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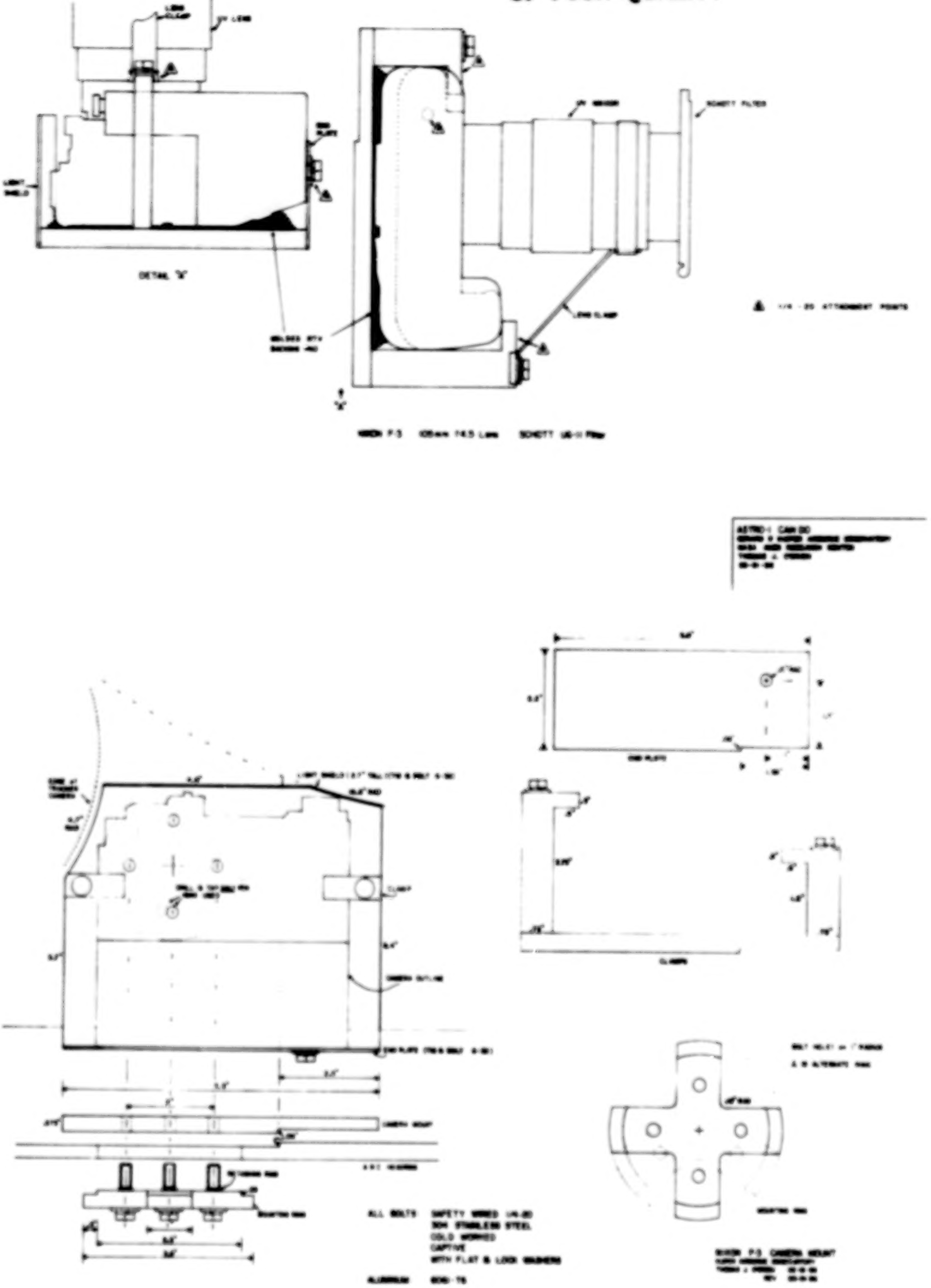

Fig-6

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both Kodak EES P800/1600 and Fiji P1600D film would be flown with the 58 mm / F1.2 lenses. The Kodak EES outperformed the Fuji as it had in the earlier tests.

It was now time to go for the ultraviolet with the 105 mm / F4.5 UV Nikkor filtered with the Schott UG-11 filter using Kodak Tri-X Pan 400 film and a 105 mm / F2.5 lens and Kodak EES covering a matching visible light field. The next flight on April 8th spent an hour and ten minutes on Halley. When the film was developed, there was Halley's UV emission, from the coma, from the ion tail, with a tail disconnection as a bonus. Unfortunately, because of the thin dry air and its greater UV sensitivity, the Tri-X also picked up a static discharge stripe (Fig-7). Examination of the film path found the source, the felt light shield on the film cartridge. On the next flight, all parts in the film path were bonded to ground, even the film cartridge. The results were slightly better, but in the end, removing the film from the cartridge and loose loading it proved the only reliable field fix. With the all-metal 250 exposure film back on the shuttle, this shouldn't be a problem but it's one more thing that must be tested.

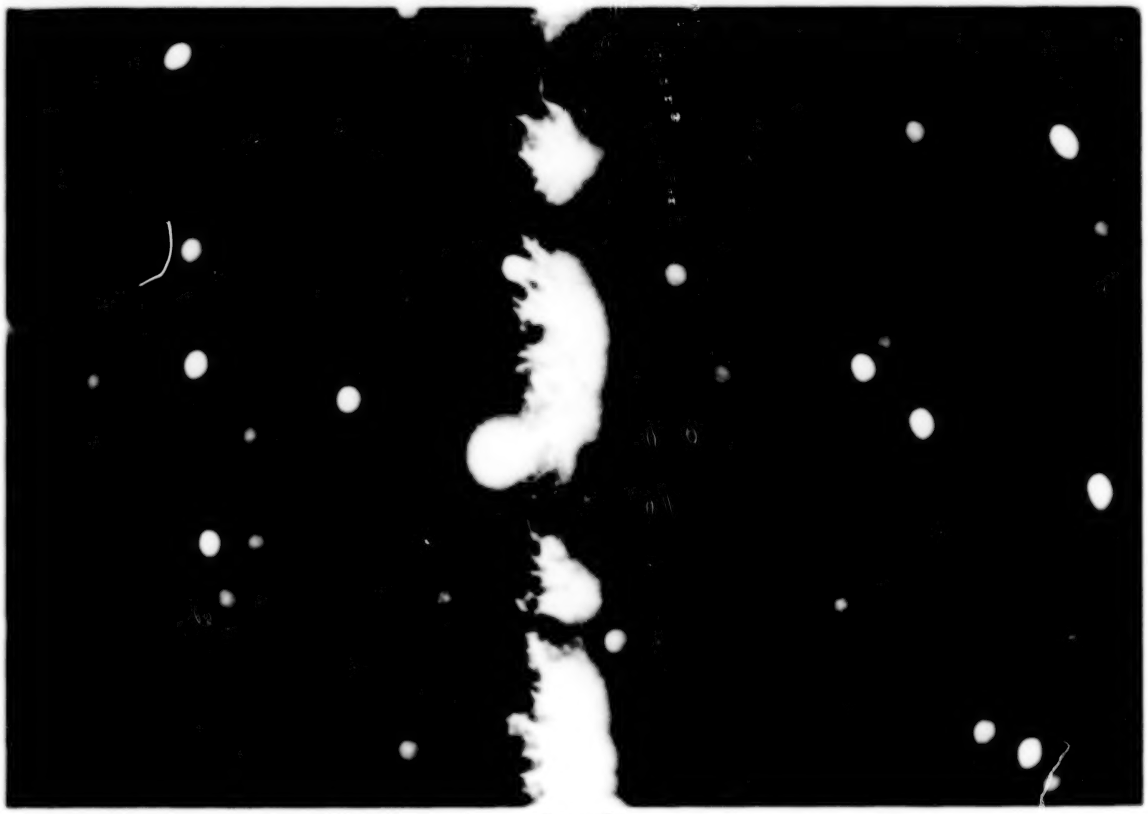

Fig-7

Postscript

Altogether, 89 objects were photographed on the KAO flights from April 5th to the end of the deployment on May 12th. The photographic results were very favorably received by the Principal Investigators and the Ames Research Center staff. Widefield photographic coverage, which was previously unavailable from the KAO, will continue now using the Astro-1 / CAN-DO control system and camera mounts. The photographs and flight logs are being compiled by NASA and the Charleston County School District into teaching packets for student use. These programs and further information on the CAN-DO project is covered in another paper presented at this Symposium.

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TO CATCH A CHILD'S IMAGINATION II

Educational Update on CAN DO

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Closing the Loop

ABSTRACT

In the field of educational activities, not unlike financial investment, high return is usually achieved only in ventures with high risk. Innovative and exotic activities such as the GAS program will invariably carry significantly more danger of failure and delay than more conservative and conventional endeavors, although the rewards can be greater also. Planning to manage such risks and building in flexibility with strong alternatives should be part of any comprehensive program.

At the G.A.S. Symposium last year, the Charleston County Public School CAN DO Project outlined an ambitious educational program revolving around the photography of Comet Halley from the Shuttle using a GAS canister. The target flight was STS 61-E scheduled for a March, 1986, launch. Such strict time constraints and highly specific mission requirements made the CAN DO program even more risky than normal. In spite of this, almost all of the planned educational goals were achieved, even after the postponement of all Shuttle activities in January of 1986.

This follow-up paper summarizes the effects of events on the program as proposed and the attempts to carry out as many of the activities as possible. It is hoped that this paper will suggest constructive ways in which to cope with the delays and mishaps that are the invariable lot of pioneers who break new ground and attempt the new and untried.

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OCTOBER, 1985 to JANUARY, 1986

At the time of the GAS Symposium in October, 1985, the CAN DO project was still far from assured of being on an appropriate shuttle flight at all. Under the rules governing the GAS queue, whether or not G324 would be eligible for a flight by March depended on several factors including whether the GAS Bridge had flown. Worse yet, the only appropriate flight, STS 61E, was already seriously overweight and no GAS payloads were planned for it, regardless of number. Despite the gloomy outlook, work proceeded in hopes of a change since the only alternative would have been to abandon all hope of photographing Comet Halley.

At the invitation of Dr. Mal Neidner, the CAN DO team was able to present its plans to the astronomers working on STS-61E's primary payload, the ASTRO ultraviolet observatory which was planning to study Comet Halley and other objects. The scientists of the ASTRO HALLEY SCIENCE TEAM, after a careful study, decided that the CAN DO camera package could serve as a useful auxiliary to their own wide field camera system pending a successful resolution of the weight problem. The subsequent removal of a communication satellite because of launch window incompatibility made the additional weight available. Suddenly, CAN DO ceased to be a GAS payload and instead became an auxiliary part of the ASTRO payload utilizing GAS technology and with GAS program technical support. From this point, the main thrust was to modify the original design to make the payload as compatible as possible with the ASTRO mission goals. These design changes, to be discussed in detail in a separate paper, included the addition of an ultraviolet camera and the design and construction of a fused silica window to allow photography at ultraviolet wavelengths. In addition, steps were taken to improve mission life in order to provide photographic coverage for more of the planned mission duration.

To insure a better percentage of "hits" than would be possible with the automatic digital video "comet detector" of the original design, it was decided to have the cameras under active Astronaut control. The cameras would be activated only at those times when the payload was oriented towards the comet and conditions suitable for good photography. Two members of the STS 61E crew, Pilot Dick Richards and Mission Specialist David Leestma came to Goddard Space Flight Center and spent a day becoming fully acquainted with the payload and the control system.

Also during this period, the payload was finished and fully tested in facilities at both Langley Research Center and Goddard Space Flight Center. All tests were successfully completed and the payload fully integrated in time to be delivered to the Kennedy Space Flight Center by the flight deadline.

With the flight seemingly assured, the NASA Educational Affairs Office, under the direct guidance of the Langley Research Center Educational Affairs Division, took an active role in publicizing the flight nationwide in an effort to recruit the greatest possible number of student participants. A twenty minute video tape was produced outlining the upcoming flight and giving the information for schools to sign up for both the Comet Halley Student Ground Research Team and for the planned educational packet to be made up using the CAN DO photos and other material.

By January, the tape was finished and a brochure already at the printer for planned national distribution. The day of the CHALLENGER tragedy was the exact day that the payload was scheduled to be delivered to the Vehicular Assembly Building for loading aboard the COLUMBIA.

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CARRYING ON

From the very moment of the Challenger disaster, there was never a serious debate about the necessity of continuing the program. Despite assurances received from many people within NASA determined to continue with the GAS program as soon as possible, there was no possible hope of any space flight during the period of Comet Halley. While long range plans to develop other appropriate future deep-space photographic targets were immediately begun, the more difficult and pressing problem was to decide how to salvage as much as possible from educational activities already under way.

The primary motivation for an aggressive alternative effort was not the loss of the scientific data. From the beginning, CAN DO has been designed as an effort to obtain good quality wide-field color visible light photographs of the Comet. While it was hoped that these photographs would compliment the other photographs being taken throughout the world by such groups as the International Halley Watch, it was clearly recognized that an army of amateur and professional astronomers would be bringing an impressive array of sophisticated equipment to bear on similar goals. The loss of the CAN DO photos was not apt to leave any very serious gap in that coverage. The program's primary goal had always been as a vehicle for student involvement and education and it was in this same area that the real loss was likely to occur.

The CAN DO project was primarily targeted at the middle school level, grades 6-8, which is a crucial period when the child first begins to develop many attitudes which he will carry on into adulthood. The typical child at this age has often not been confronted with significant tragedy or disappointment. Efforts had been successful in getting the Challenger launch carried live in a majority of classrooms in the area in hopes that the "Teacher in Space" flight would serve as a good introduction to "their" upcoming flight. Instead, these students were inadvertently brought into a situation where they felt a real personal involvement in a very dramatic and tragic event. The impression was profound, and it was felt that any action would now serve as an example, good or bad, on how to deal with tragedy and disappointment. Thousands of students now felt deeply involved with the space program and hopes and excitement had been built for a project that could not be completed as planned. To passively admit defeat and suspend the project would serve as one sort of lesson. To pick up the pieces and carry on in the best possible manner would be another very different lesson much more in the spirit of the Challenger crew and the space program itself. Therefore, with this in mind, the search for constructive alternatives was begun.

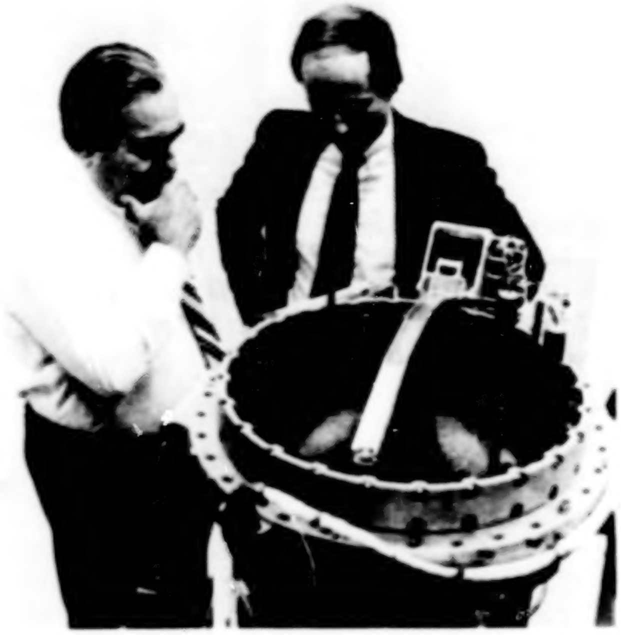

Fig. 1: Director of Special Payloads Leonard Arnowitz and Astro Mission Manager Ron Kinsley inspect the finished CAN DO payload.

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JANUARY 28, 1986 to APRIL 1, 1986

The first week following January 28 was taken up with the immediate details of closing down the space flight program including the retrieval of the payload from the Kennedy Space Flight Center. This was followed by an immediate review of the educational program in light of the new circumstances. The secondary activities including: the interviewing of senior citizens who remembered Comet Halley from 1910; the preparation of a time capsule by the Young Astronauts to be opened at the time of Halley's next apparition; the construction of a 17½ inch telescope by a local middle school; and the program of public and student "sky parties" to observe the comet and associated meteor showers were already either underway or completely planned. These programs had been specifically intended to be independent of, though complimentary to, the Space Shuttle effort and no direct impact was anticipated. In fact, these separate activities became even more important because they could be completed successfully even without pictures of the comet being made from space.

On the opposite end of the spectrum, activities specifically geared to the orbital environment such as the eleven student experiments included with the payload had to be indefinitely postponed pending resumption of Shuttle activities. All of these experiments were designed to test the effect of the micro-gravity or radiation effects of low Earth orbit on various material, both man-made and biological. No meaningful substitute could be devised and it is to the credit of the 28 young students involved that they accepted their disappointment with good grace and understanding that belied their ages.

The areas where alternatives could salvage activities were those based on the actual acquisition of photographs. These included the concurrent ground-based photography by the students for later comparison to the space-based photos, the student evaluation and interpretation of the CAN DO photos, and the publication of a post-flight educational packet. The importance of the Shuttle photos were two-fold. First, to provide pictures for comparison taken in an environment not normally available to students and such that the results might, in fact, show meaningful differences to pictures made from the ground. Secondly, to provide added interest and excitement by making their "backyard" efforts part of a larger program the included exotic activities such as space flight.

Fig. 2: Chief Machinist Cliff Harvey and the author brief STS-61E Mission Specialist David Leestma and Pilot Dick Richards on the operation of the payload.

CAN DO II - THE SEARCH FOR ALTERNATIVES

Shortly before January, a team from CAN DO and the National Geographic Society had traveled to the McDonald Observatory in Fort Davis, Texas, to conduct final film tests under darker, clearer skies than could be obtained in South Carolina. These tests had not only made it possible to select the best film, but had indicated the potential of the film and lenses to return high quality photographs under the nearly ideal conditions. One possible alternative would be to return to Fort Davis during March to take comparative photos. Other observatory sites considered were located in Hawaii and Chile, although all observatory locations were already heavily committed during the peak Comet Halley period.

During the same period, several advisors mentioned that there were two high altitude flying observatories operated by NASA which were being deployed to the Southern Hemisphere during this period. These potentially seemed to offer the best opportunity of achieving a "near-space" environment and meeting the criteria for generating interest and providing meaningfully different photos. Efforts to make contact finally resulted in discussion being opened with the Gerard P. Kuiper Airborne Observatory operated by Ames Research Center at Moffett Field, California. Observatory Director, Louis Haughney, and Mission Director, David Brown, were sympathetic and interested, but several serious handicaps make it unlikely that an effort could be launched. First, the Kuiper was busy preparing for the deployment in just a few weeks and no wide-field cameras had ever been mounted on the Kuiper. No hardware existed for such a mounting nor appropriate control equipment, and it was unlikely that any could be designed in time to be fitted and tested before the aircraft was already at Christchurch, New Zealand. Secondly, the Kuiper has its primary responsibility to the Astronomers for which each flight is dedicated. Unless it could be conclusively and unequivocally proven that the mounting of the CAN DO equipment in no way interfered with the operation of the 36-inch telescope, the equipment could not be used. This, for example, precluded the possibility of including any internal heat in the cameras as a heat source near the head ring of the telescope would completely distort data being collected by the extremely sensitive infrared sensors. This presented a considerable obstacle since no one was certain that any camera would function in the anticipated -55°C temperatures at 41,000 ft. Thirdly, CAN DO had not funds available to send a team to far-off New Zealand and support them for the time necessary to mount such a campaign, especially one so apt to not be allowed to operate. It would have been more than understandable if, in view of the time and mission pressures involved, the Kuiper Observatory had dismissed the idea with polite good wishes and regrets that this could not have been brought up when there was time to adequately consider such a major undertaking. Instead, they were encouraging and supportive and made it clear that if we could design equipment that would work without interference to the other apparatus in time, and manage to get to Christchurch, they in turn would do everything in their power to get us up and help us get our pictures.

Once more, the design team was challenged with a fourth major redesign with two weeks in which to have the plans submitted and approved at Ames. Another paper at this symposium will give the technical side of this equipment, but I want to note here that not only were the impossible deadlines met but the

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equipment performed faultlessly and created no problems for the other researchers. The Nikon cameras also rose to the occasion and experienced not one failure in cold and near vacuum far in excess of that for which they were designed. The third problem, that of funding, was solved through the continued unflagging support of the National Geographic Society, the ASTRO mission team at Marshall Space Flight Center and the NASA Education Office, who jointly provided support for a team of three to operate from New Zealand.

ABOARD THE KUIPER

The team that traveled to Christchurch included the CAN DO Principal Investigator, Chief Engineer and "Teacher-in-Space" finalist, Nikki Wenger. Ms. Wenger was chosen to insure that the experience would have a direct route back to the classroom. As part of their duties, the "Teacher-in-Space" finalists spend much of their time touring schools throughout the country and making presentations about many different NASA activities. Between April 6 and April 21, the team made six flights aboard the Kuiper Airborne Observatory and after their departure, the CAN DO equipment was used by Kuiper personnel and several university groups. Unfortunately, this period was coincident with the surprising period when Comet Halley virtually "turned off" and the comet was dim and showed only a few degrees of tail. In spite of these less than ideal conditions, good quality photographs were obtained on every comet flight. One set showed a dramatic "tail disconnection" event. In addition, some of the first ever ultraviolet wide-field photographs were made. Overall, the results obtained from aboard the Kuiper were not dissimilar to the anticipated results from aboard the Shuttle, with the exception that the Shuttle flight would have been at a time when the comet was larger and brighter. From a photographic point of view, there seemed to be little difference between the Kuiper's eight mile altitude and the Shuttle's low Earth orbit in either the visible light or the ultraviolet.

The reception to the photographs and the project was enthusiastic and the CAN DO activities were extensively covered by the New Zealand press. Members of the team, especially Ms. Wenger, were able to visit several schools both in the Christchurch area and as far away as Australia. The Kuiper crew themselves were enthusiastic about the photos and hope to have similar coverage on future missions.

Fig. 3: Teacher-in-Space Finalist Nikki Wenger mounting the cameras in the telescope bay of the Kuiper Airborne Observatory.

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Fig 4: CAN DO Chief Engineer Tom O'Brien and the author operating the control equipment on board the KAO.

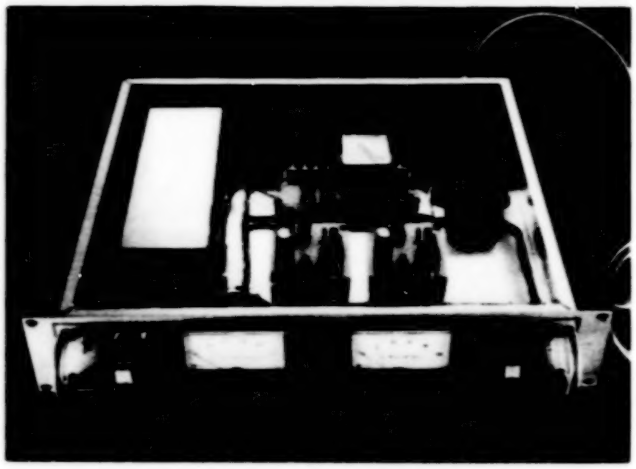

Fig. 5: The Control Unit

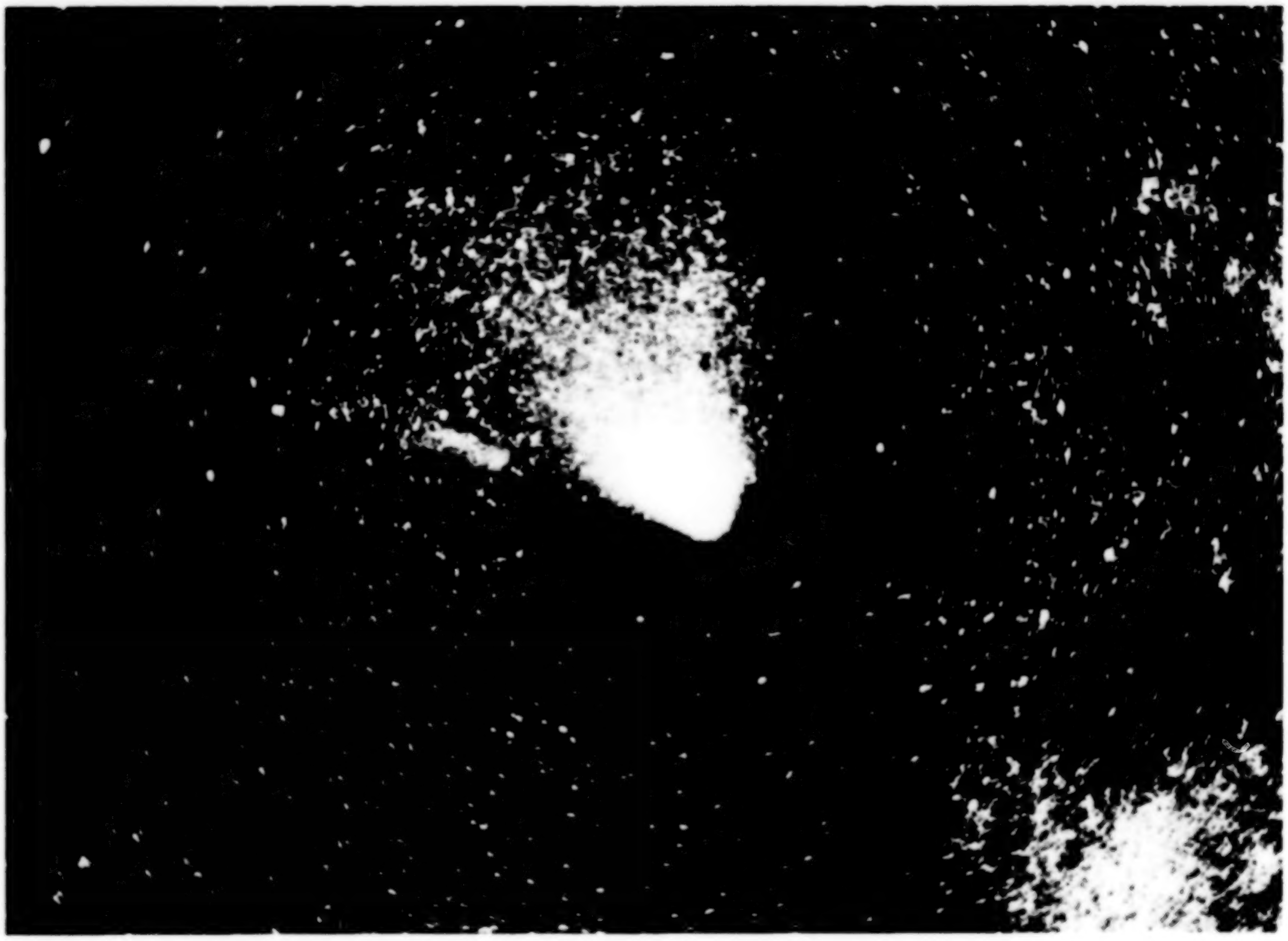

Fig. 6: Photograph of Comet Halley taken the night of April 8/9 showing a disconnection of the ion tail. Black and white reproduction of color original. 105mm f 2.5 Nikkor lens/Ektachrome EES film processed in C41/5 minute exposure.

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Fig. 7: KAO at Christchurch.

EDUCATIONAL SUMMATION

Looking back over the originally planned activities, the final scoreboard shows the following:

PRIMARY STUDENT ACTIVITIES

Junior Design Team	Completed before January
Student Space Experiments	Postponed
Student Photo Evaluation	Packets in preparation using Kuiper photos

SECONDARY STUDENT ACTIVITIES

Historical Research and Interviews	Successfully completed
Young Astronaut Time Capsule	Successfully completed
Sky Parties	Successfully completed, terrific public interest
Ground-Based Studies	Handbooks distributed, success somewhat limited by poor comet performance
Radio Monitoring of Shuttle	Postponed (Radio groups successfully used to link sky party locations)
Construction of 17.5 inch telescope	Completed in time for sky parties

CONCLUSION

While it is impossible to pretend that the loss of such a unique opportunity to photograph the comet from space was not a disappointment, the experience still was a very positive one. Educationally, we were able to complete almost all of the original goals. We developed an alternative activity that has future potential in its own right. We hopefully presented a positive example of perseverance in the face of adversity that may stand some young student well in the future. Best of all, we now have a fully built and tested payload and considerable practical experience in "near-space" photography. When our turn comes again, we will be ready to go. Older and wiser, we should be able to construct a new and better program to reach even more students. Fortunately, each new year brings fresh astronomical targets and a new group of students.

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NUSAT 1 Attitude Determination

Paul Talaga

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Abstract: This paper presents the methods for attitude determination using the static wide angle field of view sensors of NUSAT 1. Some supporting analysis and operational results are given. The system gives at best a crude attitude determination.

1. Introduction. NUSAT 1 was launched from a Getaway Special canister during May 1985. Its mission was to calibrate Air Traffic Control antennas. One factor that can help with the data reduction process is the satellite's orientation (see [3]). Therefore, attitude sensors were included in NUSAT 1.

Our purpose is to present the attitude determination process. Sections 2 - 5 give some of the analysis that went into creating a method for using the collected sensor data. In section 6 we present the process and give one example determination.

2. Overview. The shape of NUSAT 1 is a twenty-six sided polyhedron. Upon launch, the satellite was not given any initial spin, nor was there any attitude control. The tip-off angle was very small. Thus, it was initially earth oriented, i.e., rotating once per orbit with one face always towards the earth.

The attitude determination system consists of eight symmetrically located wide angle field of view (FOV) sensors. The direction of view of a sensor is the middle of one of the eight octants of a three dimensional coordinate system; sensor #3, in the first octant, has spherical coordinates $\theta=55°$, $\phi=45°$ (azimuth 45°, elevation 35°).

The sensors consist of "off the shelf" photo resistors located behind conical viewports of half angle 45° as shown in Fig. 1. The resistors are configured in a simple electric circuit so that the voltage drop across the resistor is available. This voltage reading is a maximum under no radiation and goes down in the presence of radiation. The main satellite computer can read and record the voltage at will. During prelaunch the sensors were set so that they read half scale when looking directly at the sun.

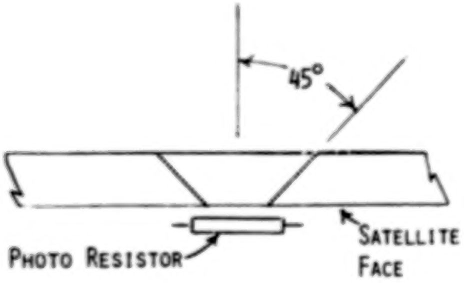

Fig. 1. Light Sensor

A sample set of data collected during one orbit on June 23, 1986 is contained in Fig. 2. For this orbit, the voltage was recorded at 40 second intervals over a period of 93 minutes. Sensor 5 failed and its data is not shown.

3. Earth Brightness. A major part of the operational analysis is the comparative effects of earth and sun light. If we assume that the earth is a uniform diffuse light source, then the brightness density (w/m^{2}sr) of earth in comparison to the sun at the satellite's position is

$$B = (1/\Omega_e)\iint_S AI/2\pi\rho^2 \, ds$$

$$= (AIr_e/2\Omega_e(r_e+a))\ln(1+2r_e/a)$$

where A = earth's albedo,
I = power density of sunlight at the earth (w/m^2),

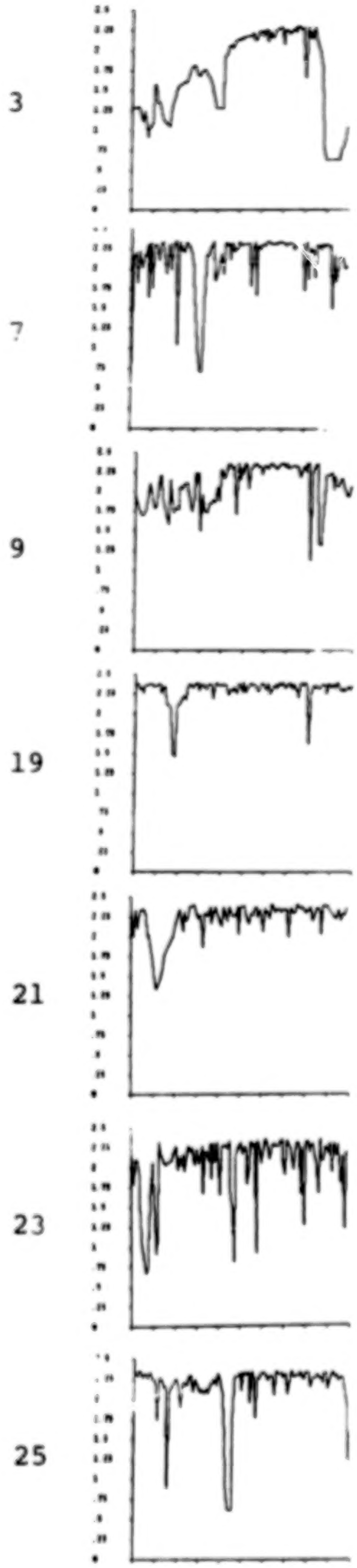

Fig. 2. Sensor data.

S - region of earth's surface that the satellite can view,
Ω_e - solid angle subtended by the earth at altitude a,
r_e - earth's radius,
and a - satellite altitude.

The relation of these parameters is shown in Fig. 3.

For NUSAT 1, we have a - 350km and Ω_e - 4.277sr. These values give B-.401 AI (w/m^2sr). The solid angle of a sensor is 1.84 sr, so that the power density of the earth light available to a sensor is .737 AI (w/m^2). Now the earth's albedo can vary between .05 for some soil and vegetation covered surfaces to .8 for some types of snow and ice or clouds [1] with an average of .3. Thus we have for the power density of the earth light available to a sensor

A	Earth light power density
.05	.03787 I
.3	.2271 I
.8	.5897 I

This analysis indicates that earth light will not have much effect on the recorded output. Recalling that full sun viewing will cause a reading of 1/2 down, earth light alone should only cause a reading of at most .3 down from maximum. On the other hand our model is not complete. It does not take into account any specular sun reflections observed in photographs of the earth. The earth is more like a uniform, diffuse, reflecting Lambert sphere [2] with an indistinct bright region midway between the subsolar point and subsatellite point.

4. Viewing Conditions. Two other important questions in the basic analysis are the number of sensors that can view the earth or the sun at a given time, and whether a sensor can view both the earth and the sun at the same time. These questions can be answered by considering the satellite lighting conditions. For this analysis we will think of the satellite as a sphere.

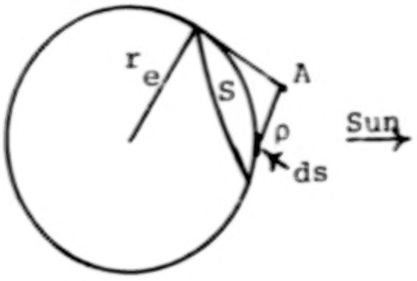

Fig. 3. Earth region visible at point A.

At an altitude of 350 km, the earth subtends an angle of 142° and the area of the satellite that can not receive light from the earth is a cone of half angle 19° centered about the zenith. The FOV is 45°, therefore the directions a sensor can point and not receive earth light form a cone of half angle 64° centered about the zenith. Half the satellite can receive light from the sun, but the 45° FOV reduces the set of directions in which a sensor can receive light from the sun to a cone of half angle 45° centered about the sun direction. Summarizing, a sensor receiving earth light is within 116° of the nadir and a sensor receiving sunlight is within 45° of the sun direction.

To determine the possible combinations of sensors receiving earth light or sun light a three dimensional physical model was constructed. The positions of the sensors were plotted as points on the surface of a sphere. Then small circles of radii 45° and 64° were plotted about each point. If the sun's direction is in a circle of radius 45° then that sensor can receive sun light. If the zenith is in a small circle of radius 64°, then that sensor can not receive earth light. The intersections of the small circles thus form regions that correspond to the combinations of sensors receiving sunlight or receiving no earth light. By analyzing the intersections, it was found that at least four sensors must receive earth light and at most seven sensors can receive earth light at a given time. Zero, one, or two sensors can receive sunlight at a given time.

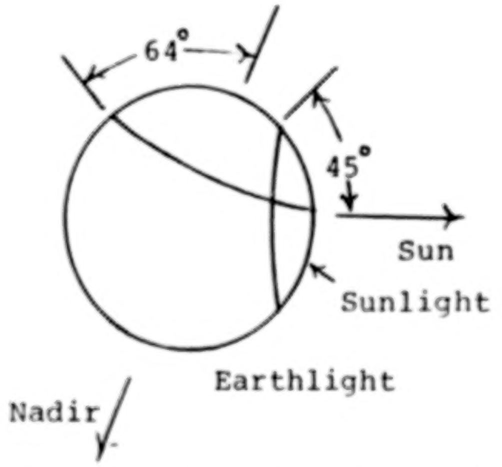

Fig. 4. Satellite lighting conditions.

Whether a sensor can simultaneously receive earth and sun light depends on the position of the satellite in its orbit. A tyical situation is shown in Fig. 4. Of particular importance is the fact that there is only a small region of satellite positions with respect to the earth and sun in which it is impossible for any sensor to simultaneously receive earth and sun light. This is shown in Fig. 5.

5. Dynamics. From experience it has been found that the rotational motion of a free

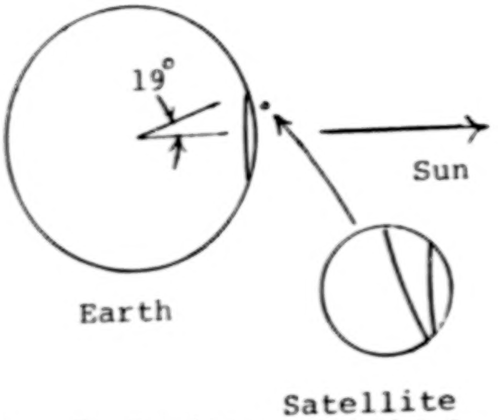

Fig. 5. Positions in which no sensor can simultaneously receive earth and sunlight.

floating satellite tends to slow over time. This is explained by the absorption of kinetic energy in the motion of internal components, such as vibration of wires, antennas, etc. Further, the motion tends toward a pure rotation about the principal axis with the largest moment of inertia [2].

The moments of inertia of NUSAT 1 were computed after launch using incomplete data, but taking into account the most massive components. They were $I_x = 94.3$, $I_y = 94.2$ and $I_z = 83$. Therefore any rotational motion should tend toward a pure rotation about a direction somewhere in the xy plane.

Initially the satellite had an earth orientation, rotating once per orbit. After one year, the attitude should be almost fixed inertially. It might be slightly drifting and slightly rotating about an axis in the xy plane.

6. Attitude Determination. To form a database, sensor readings were recorded at regular time intervals for an entire orbit. This was done every few weeks starting in January 1986. It was also performed on four different days during the third week of

June 1986.

An examination of all the data reveals several facts. Some features are coupled to the orbit but remain generally the same over the six month period. There is usually one sensor (#3 in Fig. 2) whose readings are slowly varying and remain below a certain level during the period of sun exposure. This indicates that the satellite has very little rotational motion and that the anomalous sensor is facing the sun. In addition to the short duration spikes which may be due to noise or a corrupted bit of data downlink, there are short periods from 2 to 10 minutes during which a sensor is receiving a lot of radiation (voltage down by 50% to 70%). Some of these periods occur just before entering and/or just after exiting the earth's shadow. The only feasible explanation for these is the sighting of bright spots on the earth, possible clouds and/or the sun reflection areas mentioned in Section 2.

Assuming the satellite is rotating, drifting at a very slow rate, less than one revolution per week, we can obtain a general idea of the attitude from the data of Fig. 2. For this data using a starting time of 0, the satellite had the following orbital positions:

Time	Position
19 min	Top of the orbit
42 min	Terminator
48 min	Earth shadow entrance
80 min	Earth shadow exit
86 min	Terminator
90 min	Orbit completion

By the top of the orbit we mean the position where the angle between nadir and the sun is the greatest, 141° for this orbit. Sensor #3 is generally towards the sun, receiving very little earth light after the top of the orbit, and receiving a good deal of earth light before entering and after exiting the earth's shadow. Sensor #25 must be facing back towards the terminator as the satellite passes into night. Sensors 7, 9, 19, 21, and 23 all seem to be receiving some earth light as the satellite crosses the sunlit earth. Sensors 7, 9, 23, and 25 are generally toward the earth at the first terminator crossing. With this information and a scale model of the satellite one can get an idea of the attitude by positioning the model to account for the readings at various times during the orbit.

7. Conclusion. Our method gives a rough idea of the attitude, i.e., which side of the satellite is facing the earth; this is sufficient for present operations. It might be possible to construct a computer algorithm for attitude determination using statistical method, e.g., the q method [2], but results more accurate than ±20° seem unlikely. Others [private communications] have tried to get more accurate results from similar wide angle sensors with little success.

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NUSAT 1 METHODS FOR RADAR FIELD STRENGTH MEASUREMENT

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Abstract: The methods for obtaining the gain pattern of an Air Traffic Control Radar using the data collected by NUSAT 1 are presented. The basic equations for this are given; these require an independently determined satellite attitude. In addition we show how simultaneous measurements made by separate channels can be related to obtain a single axis attitude, i.e., the direction of propagation of the incident radiation, and the power density of the radiation. This is done by solving a system of three algebraic equations.

Introduction. NUSAT 1 was the first satellite to be launched from a Getaway Special Cannister. It has six L-band channels which are driven by six orthogonally directed antennas. The purpose of these systems is to detect Air Traffic Control Radar (ATC) transmissions and measure the power density of the incident radiation, thus allowing the gain pattern of the radar transmitter to be determined. Since the satellite is free floating (no attitude control) and since the gains of the satellite's receiving antennas are not unidirectional a fundamental problem arises in the determination of the direction of propagation (with respect to a satellite based coordinate system) of the incident radiation. To surmount this problem a crude attitude determination system was included in NUSAT 1. It will not give an attitude accurate enough for data reduction.

The purpose of this paper is twofold; one, we will present the equations needed to calculate the gain of the radar transmitter and power density of the radar wave. These can be used if an independently determined attitude is available. Two, we will also show how three simultaneous measurements made by three

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separate channels can be related to obtain a single axis attitude; i.e., the direction of propagation of the incident radiation, and the power density of that radiation. This is done by solving a system of three algebraic equations. In addition, we will give a short error discussion to indicate the type of accuracy available.

1. Overview of NUSAT 1 For those readers who are unaware of the need and current methods for obtaining the power pattern of an ATC radar, we will give a brief summary of the situation; [1] contains more detailed information.

Air Traffic Control Radar The ATC radar transmitting antennas rotate at a rate of one revolution in four to ten seconds. They have an elevation beam width of about 40 degrees (the lower 15-20 degrees is used to detect aircraft) and an azimuth beam width of 2 degrees. They transmit on a frequency of 1030 Mhz. If the antenna is pointing too low, then ground interference causes nulls and lobes. So for safe operation in controlling air traffic, the radiation pattern for many different azimuthal orientations of the radar antenna is desired. In lieu of this, at least the location of the nulls and lobes.

The Satellite. The shape of NUSAT 1 is a twenty-six sided polyhedron. Upon launch, the satellite was not given any initial spin, nor is there any attitude control. Thus, the satellite's attitude is allowed to drift.

The satellite has a rather crude attitude determination system - eight symmetrically located wide angle field of view sensors (detecting radiation primarily in the visible region of the spectrum).

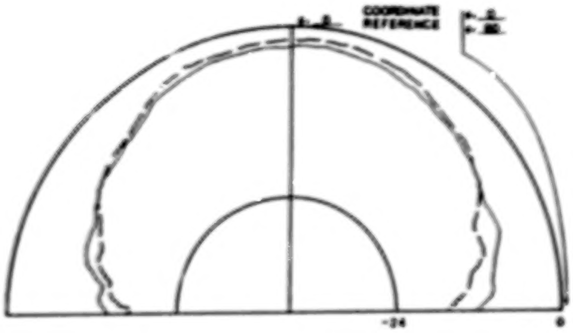

Fig. 1. Partial power gains in the horizontal G_ϕ ---- and vertical G_θ ——.

The features of present interest to us are the six L-band antennas whose major axes are directed in six orthogonal directions. Each is a circularly polarized double Archimedes spiral antenna with a nominal total gain of 1.4 dB. One cut of the pattern (partial power gains in the horizontal and vertical directions) of a typical antenna is depicted in Fig. 1. Note that the usable range is a hemisphere centered about the antenna's major axis and that the gain is down by 6 or 7 dB at 60 degrees.

2. The Basic Equations. The calculation used to determine the gain of a radar antenna can be split into two steps. First, the measured value of the received power is used to find the power density of the incident wave at the satellite. Then this value is combined with data from orbital prediction routines to compute the gain of the radar. These calculations are based on the transmission equation.

The fundamental equation governing power transmission is the Friss Transmission Equation [2, Sec 2.17]:

$$P_r = (\lambda/4\pi r)^2 G_r(\theta_r,\phi_r) \times G_t(\theta_t,\phi_t) pe P_t \qquad (1)$$

where

P_r - power supplied by the receiving antenna,

P_t - power applied to the transmitting antenna,
r - distance between the antennas,
e - total efficiency,
p - polarization loss factor,
$G_r(\theta_r,\phi_r)$ - isotropic gain of the receiving antenna in the (θ_r,ϕ_r) direction,
$G_t(\theta_t,\phi_t)$ - isotropic gain of the transmitting antenna in the (θ_t,ϕ_t) direction.

The relation between these parameters is shown in Fig. 2.

The power density W of the incident electromagnetic wave is related to the received power by

$$W=P_r 4\pi\lambda^{-2}(G_r(\theta_r,\phi_r)p)^{-1}. \quad (2)$$

By using this in equation (1), one can show that the desired quantity $G_t(\theta_t,\phi_t)$, the gain of the radar antenna-ground interference in the direction (θ_t,ϕ_t), is

$$G_t(\theta_t,\phi_t) = 4\pi r^2 W/P_t e \quad (3)$$

In logarithmic decibel form this becomes

$$[G_t(\theta_t,\phi_t)]_{dB}=20\log r + [W]_{dB} + 10\log(4\pi/eP_t),$$

where the last term may be dropped if the absolute gain is not desired and the quanities P_t, e are nominally constant.

In our application, P_r is measured by the satellite; then equation (2) is used to calculate W. In (2) the angles θ_r,ϕ_r represent the direction of propagation of incident wave; i.e., the direction of the ATC radar in a satellite based coordinate system. These can be found from an attitude determination system or they can be computed simultaneously with W. In addition, the polarization loss factor, p,

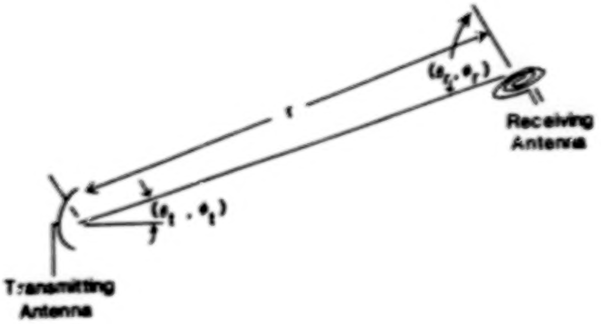

Fig. 2. Relation of parameters for power transmission.

must be evaluated. The evaluation of p and computation of W will be discussed in more detail in the next section. Once W is found, it can be used in (3) to get the gain of the radar antenna. Here, the variables r,θ_t,ϕ_t are the spherical coordinates of the satellite in a local coordinate system based at the radar antenna. These can be found from orbital prediction routines.

3. Computation of power density and the polarization loss factor.

The power density W of the incident radar wave is computed using (2). Nominally, the radar wave is linearly polarized and the receiving antennas are circularly polarized; so p may be approximated by 1/2. For more accuracy p needs to be evaluated; this may be done using the gain measurements performed on the receiving antennas.

The antennas were measured using a modified version of the Multiple-Amplitude-Component method. The entire gain pattern (letting θ_r,ϕ_r range over useful values, a hemisphere about the major axis) of each antenna was measured with a linearly polarized transmitter oriented at angles ψ of 0, 45, 90, and 135 degrees (see Fig. 3). This resulted in a measurement of the partial power gains G_ϕ, G_{45}, G_θ,

G_{135} respectively in the direction (θ_r,ϕ_r).

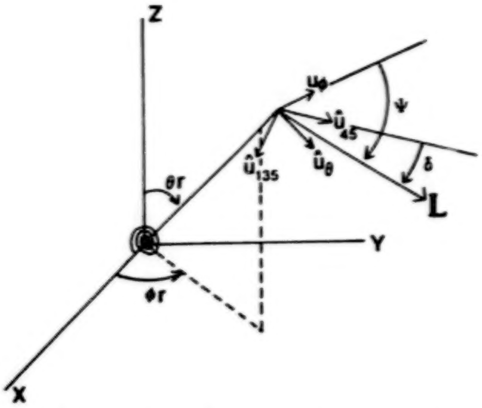

Fig. 3. Direction of polarization, **L**, of wave propagating from direction (θ_r,ϕ_r).

Letting **L**, in Fig. 3, represent the electric field of the incident wave allows the polarization ratio to be related to either of the angles ψ or δ. By using the angle ψ and, assuming that the wave is perfectly linear; i.e., that the power in the direction perpendicular to **L** is zero, one can show that

$$p = \cos^2\psi + \tau^2\sin^2\psi + \tau\sin 2\psi\cos\beta/(1+\tau^2)$$

where τ,β are the polarization ratio and relative phase angle of the receiving antenna in the direction (θ_r,ϕ_r). A similar equation is available for p using the angle δ. Note that for a perfectly circular antenna we have $\cos\beta=0$ and $\tau=1$ so that p reduces to 1/2. We also note that there is the option of approximateing $\cos\beta$ with a nominal value for each antenna. If this is done, only the measurements G_ϕ, G_θ need to be performed and

$$G_r p = G_\phi\cos^2\psi + G_\theta\sin^2\psi + \tau\sin 2\psi\cos\beta G_r/(1+\tau^2).$$

Since a complete set of four measurements are available for NUSAT 1, both τ and β can be found for each direction (θ_r,ϕ_r). Omitting the intermediate steps, we get two different equations to use for the product $G_r(\theta_r,\phi_r)p$ in equation (2). Using the angle ψ we get

$$G_r p = G_\phi\cos^2\psi + G_\theta\sin^2\psi + (1/2)\sin 2\psi(G_{45} - G_{135}). \quad (4)$$

Using the angle δ we get

$$G_r p = G_{45}\cos^2\delta + G_{135}\sin^2\delta + (1/2)\sin 2\delta(G_\theta - G_\phi). \quad (5)$$

If the satellite's attitude can be found, then θ_r,ϕ_r can be determined from the relative location of the radar and the satellite at the time the mesasurement was made. Further, ψ and δ can be found by applying the attitude matrix to a vector in the direction of the local vertical at the radar antenna. Thus, $G_r(\theta_r,\phi_r)$ can be determined from either equation (4) or (5). For better accuracy, the equation that has the smallest value for $\sin 2\psi$ or $\sin 2\delta$ should be used (subtraction produces a loss of significance in the third terms).

Alternately, the power density, W, and the angles θ_r,ϕ_r can be determined simultaneously by relating three received power levels. For this though, the polarization loss factors must be approximated by 1/2. Recall that NUSAT 1 has six L-band antennas oriented so that their major axes are directed in the six orthogonal directions. When the satellite is not in a null of the radar's radiation pattern at least three channels will be able to detect a signal. The geometry is shown in Fig. 4, where the major axes of the antennas which

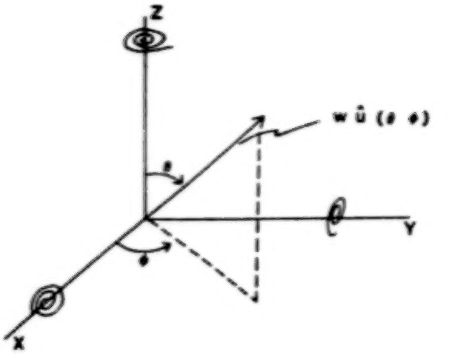

Fig. 4. Three L-band antennas and the direction of the incident wave with power density w.

are able to detect a particular signal have been placed along the x,y,z directions. From equation (2) we have for the three channels:

$$\begin{aligned} P_1 &= (\lambda^2/4\pi)G_1(\theta,\phi)p_1W \\ P_2 &= (\lambda^2/4\pi)G_2(\theta,\phi)p_2W \\ P_3 &= (\lambda^2/4\pi)G_3(\theta,\phi)p_3W \end{aligned}$$

where $G_i, P_i, p_i; i=1,2,3$ are associated with channel i and θ,ϕ give the direction of the radar in body coordinates. If the polarization loss factors are approximated by 1/2 this system can be solved for W,θ,ϕ. The gain functions $G_i(\theta,\phi)$ are only known through test measurements, yet any of several numerical methods can be used to solve this system. If the chosen method requires the partial derivatives of the functions G_i, then it might be necessary to smooth these measurements. Actually this system should be solved in logarithmic decibel form:

$$\begin{aligned} [P_i]_{dB} = {} & 10\log(\lambda^2/4\pi) \\ & + [G_i(\theta,\phi)]_{dB} + [p_i]_{dB} \\ & + [W]_{dB}, \qquad i=1,2,3. \end{aligned}$$

Combining each $[P_i]_{dB}$ with $10\log(\lambda^2/4\pi)$ and using P_i to denote the combined quantity this system becomes, with the dB subscripts dropped

$$\begin{aligned} P_1 &= G_1(\theta,\phi) + W + p_1, \\ P_2 &= G_2(\theta,\phi) + W + p_2, \qquad (6) \\ P_3 &= G_3(\theta,\phi) + W + p_3. \end{aligned}$$

For actual computation, each p must be approximated by -3dB.

4. Preliminary error discussion. We now give an error discussion to indicate the origin of major errors and to realize the type of accuracy available. We will only give a short discussion of the errors as the complete error analysis is quite lengthy and is still in the process of being completed.

The gain of the radar antenna in the direction (θ_t,ϕ_t) is computed from (3) with the power density being calculated from (2). From (3), the relative error in $G_t(\theta_t,\phi_t)$ is:

$$\Delta G_t/G_t = 2\Delta r/r + \Delta W/W + \Delta e/e + \Delta P_t/P_t.$$

The angles θ_t,ϕ_t and the distance r are found from orbital prediction routines which are usually quite accurate. The efficiency e and power supplied to the transmitter P_t are close enough to being constant that they will also not contribute much error. The relative error in the power density $\Delta W/W$ will be at least two orders of magnitude larger than the others. It can be found from (2),

$$\Delta W/W = \Delta P_r/P_r + 2\Delta\lambda/\lambda + \Delta G_r p/G_r p.$$

the received power P_r is obtained from measurements of the signal in the L-band channels. A calibration can be carried out for each channel, thus keeping $\Delta P_r/P_r$ comparatively small. The relative error in the wave length $\Delta\lambda/\lambda$ will be very small, the relative error in neglecting the doppler shift is .01 %. The term

$G_r(\theta_r,\phi_r)$ will produce the largest error.

An error analysis for equations (4) or (5) is in progress, but no results are available at this time. An indication of the error was obtained by considering G_r and p separately. If the angles θ_r,ϕ_r are found independently from W, then the error in $G_r(\theta_r,\phi_r)$ will depend on the errors in θ_r and ϕ_r; the accuracy of the gain measurements of the receiving antennas; and the variation of G with respect to θ_r,ϕ_r. If the angles θ_r,ϕ_r are known to be within .5 degrees, then $\Delta G_r/G_r$ will be bounded by 12% since the gain measurements indicate that the variation is bounded by .25 dB/deg. Some quick estimates of the error in approximating p by 1/2 indicate that it will average about 1.2dB but may be as high as 2 dB.

Thus, the total error in finding the radar gain $G_t(\theta_t,\phi_t)$ given values of θ_r,ϕ_r accurate to within .5 degrees and aproximating p by .5 will be on the order of 1.6 dB but could be as much as 2.3 dB.

To give a preliminary indication of the error in determining θ_r,ϕ_r and W simultaneously, the author worked several examples. These gave the following bounds:

$$\Delta\theta, \Delta\phi \leq 10 \text{ degrees},$$
$$\Delta W \leq 1\text{dB}.$$

5. Conclusion As yet the satellite has not made any actual radar measurements. Therefore, no test results are available for presentation. But, as reproduced here, the necessary equations are in place for calculating the ATC radar gain in case some measurements are made. These same equations will be needed for the second satellite to attempt an ATC radar calibration, NUSAT2.

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G-300, THE FIRST FRENCH GETAWAY SPECIAL
MICROGRAVITY MEASUREMENTS OF FLUID THERMAL CONDUCTIVITY

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Abstract

On earth thermal conductivity measurements on liquids are difficult to perform because thermal motions due to convection. In microgravity the convection due to buoyancy is evanescent and we expect a strong lowering of Rayleigh and Nusselt numbers. Three low viscosity liquids are selected to carry out the measurements : distilled water (standard) and two silicone oils. We use a modified "hot plate" method with a simplified guard ring, the lowering of convective motions let us to use in the experimental cells larger interplate distances and/or temperature differences than in earth measurements so the accuracy must be improved. Comparisons between earth and orbit results may help to understand the convection occurence in our cells.

Introduction

In 1979, with an advertising sake, Matra Company had reserved a Nasa Getaway Special (GAS) and organized a competition between French universities to promote space research. We won this challenge and so Matra gave us the opportunity to carry out our first experiment in microgravity. The objective of our payload is as follows. On earth the thermal conductivity measurements are difficult to perform on fluids because thermal motions due to convection. This later comes from the coupling between gravity field and temperature gradients in the experimental cell. In orbit if we assume a zero gravity, the convection due to buoyancy disappears and the accuracy on thermal conductivity will be improved specially with low viscosity liquids. The objective of G-300 is to perform such measurements on three liquids : distilled water (standard) and two silicone oils. In this paper we described the methodology of our instrumentation and the solutions we have found to fulfill the GAS requirements.

Support Structure

To support our payload we use 32 from the 45 holes available on the Experiment Mounting Plate (EMP). As seen in the perspective view (Fig. 1), G-300 payload is cantilevered from EMP and consists of an intermediate plate and a bottom plate separated by four U-shaped struts. The sockets of these struts are bolted at 90° intervals on the EMP and bottom plates and they are fastened to intermediate plate by brackets. The bottom plate is supported laterally by four adjustable bumpers covered with Viton, these later have the same curvature as the inner canister wall and can be pressed against it. The battery box is located between EMP and intermediate plate and bolted to them. The electronic rack is positioned between intermediate and bottom plates and secured to them. The experiment items consist of three tandems each including two cells. Each cell is mounted on an aluminium alloy support bolted to EMP and fastened to intermediate plate via a fiberglass plate (see photograph below). The design philosophy used in this payload has been to perform a good thermal path between experiment cells and the EMP to obtain a heat sink that evacuates the energy provided by heaters. A passive thermal control is sufficient in our case. The thermal paths of the various cells are decoupled at maximum taken into account the mechanical stiffness. The structure configuration provides a center of mass relatively closed to the EMP. The mass distribution is approximately as follows :

. Support structure items	16 kg
. Battery box (filled)	30 kg
. Electronic rack (filled)	6 kg
. Experimental cells and their supports	25 kg

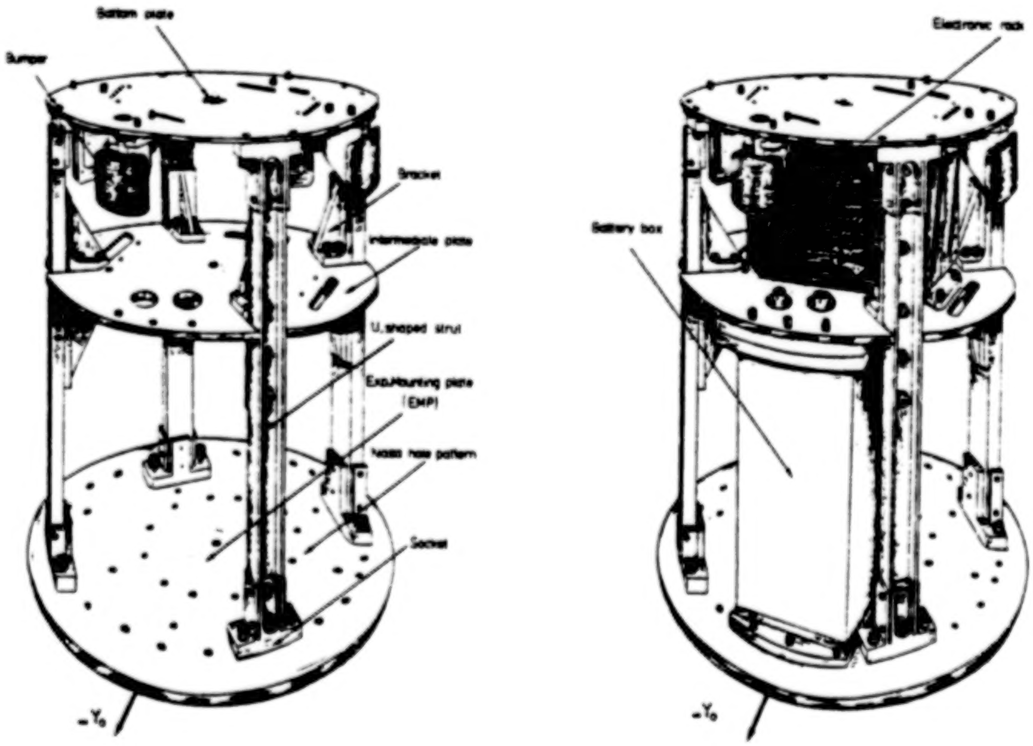

Fig. 1.G-300 Payload structure

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Measurement cells - Theoretical aspects

To carry out our experiments we have studied and manufactured a set of liquid containers adapted to thermal conductivity measurements. The cells are assembled in three tandems and each of them includes two cells filled with the same liquid. On tandem is filled with distilled water and the others with two silicone oils having a different viscosity. The shape of all tandems and cells are the same but in a tandem the two cells differ by the liquid thickness, this later varies from 2 to 5 mm. To avoid some corrosion of cells by the tested liquids (mainly distilled water) the inside part of the six cells are anodized after machining. Long duration tests (several months) are demonstrated the effectiveness of such a protection. Figure 2 shows the details of a tandem. The heater is a circular alumina plate covered with two silver contacts, a resistive path and a vitreous enamel (thick film technology). Two copper wires are soldered to silver contacts to power the heater (maximum current 0.5 A). The heater is stuck to the fiberglass cover with a glue giving a good mechanical strength in the expected temperature range - 20/+70°C. The liquid is in direct contact with the heater except for distilled water where a thin layer of silicone varnish is deposited on. In the center of the alumina heater and opposite to the liquid a thermocouple (TC) is stuck with conductive epoxy, its small wires (0.1 mm) are directed through the fiberglass cover by a small bore in which they are stuck. Six other thermocouples are glued on the fiberglass cover. Two other thermocouples are fixed in the body of cell machined with aluminium alloy. Above the heater a platinum resistance temperature detector (RTD) is glued to fiberglass cover. The RTD corresponding to a tandem are positioned face to face and wired as two branches of a bridge. The unbalance of this bridge provides an error signal needed to adjust the electrical power injected to one heater (slave) whereas the other is kept constant (master). This servo-controlled power supply provides a near zero temperature gradient between the two fiberglass covers so thermal lossed are minimized. From the thermocouple voltages and with the measured electrical power, the thermal conductivity of liquid can be calculated. The cells are bolted to the cell stands which are attached by three bolts to the EMP. The two cells forming a tandem are joined by a lexan tube bolted to the cells. On each cell the two filling ports are opposite, one of them includes an expansion tube needed to accomodate the variations with temperature of the liquid volume.

They are usually three modes of heat transfer in liquids : conduction, radiation and convection. These modes are inherently linked in the one-G environment of earth and it is empirically difficult to separate their individual contribution. The convective effects may be determined by comparing the results of the experiments performed in space and on earth. Furthermore the space measurements may provide more accurate results if the convection is negligible. Various experimental techniques are used to obtain the thermal conductivity of liquids (Tsederberg, 1965). We have chosen a modified "hot plate" method with a simple guard ring to reduce heat losses above heaters. On the theoretical point of view the analysis of heat transfer is essentielly different in the case of static liquid or when motions occur.

If the convection is negligible we may found the temperature field in our cell by two methods.

The first is an analytic one and starts from classical heat equation with idealized conditions along the limiting surfaces of liquid. The second one is a relaxation method. We have attached several thermocouples in our experimental cell (Fig. 2) from their signals we may calculate the temperature field anywhere in the liquid and by integration the heat flux.This last method is more realistic than

the former one but rests on experimental values.
If convection is present the thermal conductivity values increase (Fritz and Poltz, 1962 ; Poltz and Jugel, 1967) and calculations are more difficult. Usually to observe the convection phenomena the Rayleigh-Benard set-up is used, the liquid is placed between two isothermal planes and heated from below and convection occurs when the Rayleigh number reachs 1700. Our cell geometry is very different, firstly the heat comes from above the liquid layer and secondly the heater has a limited area so the convection occurence is more difficult to estimate. As the temperature difference increases small liquid motions must take place near the heater limits and progressively these motions fill the whole layer. It seems that the transition to convection is smoother than in Rayleigh case and the critical value appears smaller (~ 700). A more detailed analysis will be performed to clear this aspect.

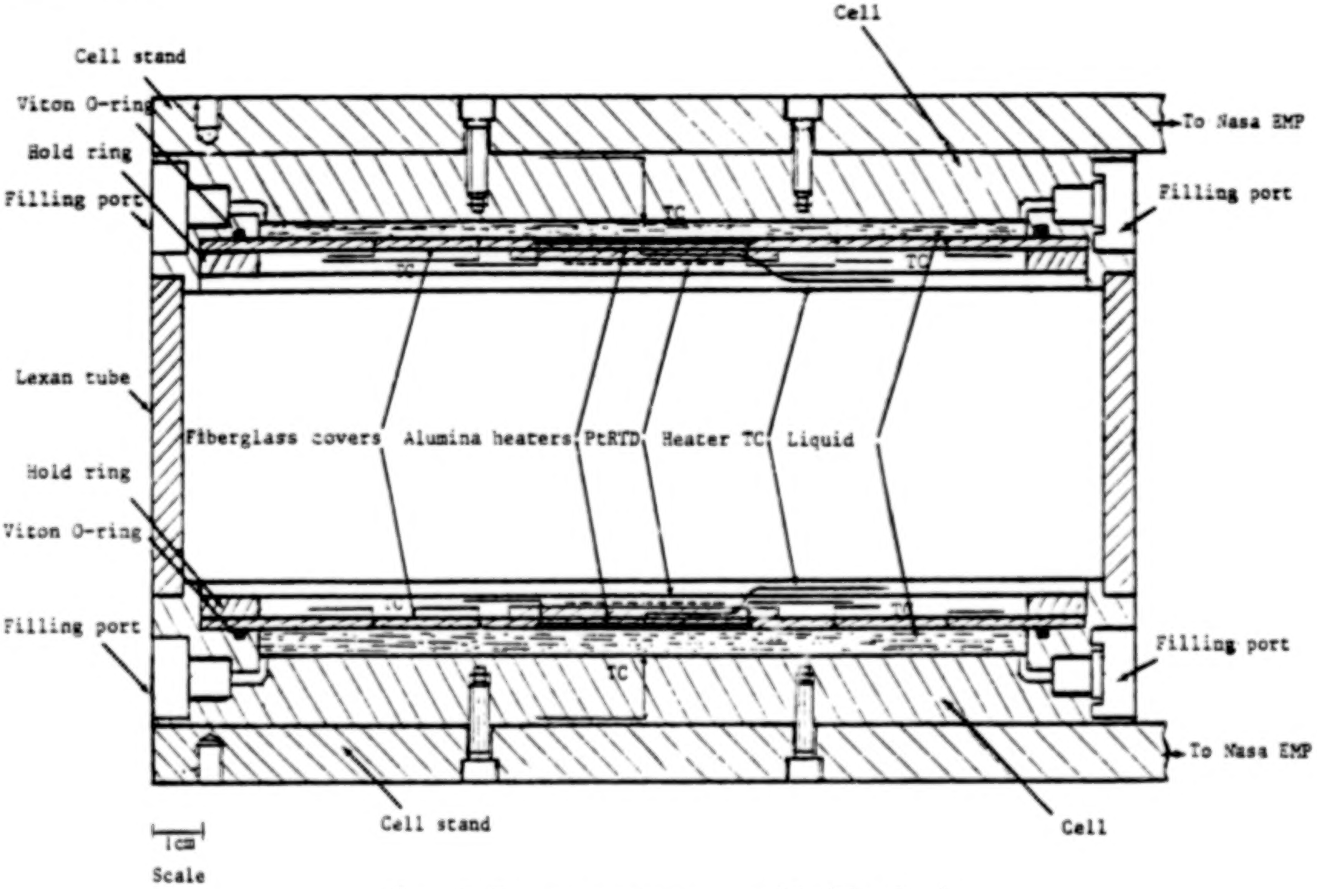

Fig. 2.Two measurement cells(Tandem)

Power supply

Our paylaod is powered by only one battery. We have selected silver-zinc cells because their good charge retention and their reliability. The electrical energy to perform our experiments must be sufficient to power both electronic cards and cell heaters (only one tandem works at a time). The battery consists of twenty Ag-Zn cells jointed together in two stacks of ten cells each so the power connector provides ± 15 V respect to ground (junction of stacks). The cell capacity is 40 Ah and the stored energy reachs 1200 Wh. The battery housing is manufactured with aluminium alloy and must be gas tight because H_2 production (zinc corrosion) along standby. Furthermore this box is connected to the outside of canister by two differential pressure relief valves provided by Nasa. Two connectors are fixed on the box cover, one of them delivers power and the other is used both to control each cell voltages at KSC integration and to transmit the battery temperature (two thermistors located in the housing). The experiment heaters are powered from the battery output via the servo-control card (see below) whereas the electronic cards are fed from a switching power supply giving regulated voltages (+ 5 V, ± 15 V). Along the mission the expected currents are relatively low (max. 1 A, mean 0.4 A) but the total experiment duration is long due to the thermal time constants of measurement cells. The available energy is large enough to power our payload along 60 h at minimum. The battery output (± 15 V) is controlled (on/off) by the payload power contactor (PPC) located in the GAS interface and switched by astronaut. Two malfunction inputs are directed from our electronic rack to the Nasa PPC and if anyone is activated the power is interrupted, they are :

. Overtemperature of battery housing, more than 70°C (Thermistor controlled)

. Undervoltage of any battery stack, less than 12 V.

Electronics

When the power is switch on the microcontroller start the experiments, collect the data and store it for use back on earth. The design of this control system must take into account reliability, power consumption, weight and compactness. We have studied and manufactured seven dual-sided PC Boards located in an electronic rack and using CMOS integrated circuits. Industrial grade components are soldered on the spare cards and military grade ones on the flight cards. Though the industrial temperature range - 25/+ 85°C will be adequate in the expected GAS thermal environment (see below) the military components give a better margin of safety. Figure 3 gives the system block diagram and the electronic cards are as follows :

. CPU/ADC/MEM PC board includes the microprocessor NSC 800, I/O ports and timers, the monitor ROM (8 kbytes), a buffer RAM (8 kbytes), two independent memories used to store the data (EPROM 64 kbytes), the ADC (12-bit word format) and a RS 232 interface. The quartz frequency is 204.8 kHz.

. Three low level cards amplify the thermocouple and RTD signals issued from each experiment tandem.

. High level card (or housekeeping card) monitors the temperature in various locations of the payload (Thermistors) and checks the voltage of the battery and its temperature. If a problem occurs the malfunction input is activated via a non-maskable interrupt of microprocessor.

. The servo-power PC board controls and provides the programmed powers to the master and slave heaters of the working tandem. Heater currents are fused and measured on this card.

. The power/interface board houses the DC/DC converter giving from the battery output the regulated voltages (+ 5 V, ± 15 V) needed for electronic components. An output connector from this card is used to conduct the malfunction signals to Nasa PPC and the RS 232 bus to outside the GAS canister. This bus is used both for test purpose and to retrieve the data from EPROM.

Operational scenario and software

The G-300 payload requires a minimum duration of two and half days and a "turn-on" signal for the experimental package as early in the Shuttle mission as possible to get satisfactory thermal environment (see below). When the power is delivered the microprocessor (µP) is reset and begins the monitor program stored on ROM. A twin-pack of cells is selected and a defined electrical power is supplied both to the master and slave heaters of this pack. The servo-system adjusts continuously the slave input to obtain a zero temperature gradient between the two fiberglass covers. The thermocouple voltages, the heater currents and the input connector temperature are measured and stored in RAM. Also a mean value of slave voltage is calculated and stored. The RAM values are stored in EPROM in two separate sequences via EPROM programmer. Each experiment duration is two hours at maximum, the stability of temperature gradient through the liquid layer or the elapsed time gives the end signal for this purpose. When it takes place the heater powers are switched off. Depending on the temperature of surrounding structure, a dead time may occur after which heater powers are injected on another twin. A timer is located on CPU card and time is read and stored at the beginning and the end of each experiment (2.8 s resolution). Sequentially the µP activates the three packs following the monitor program and the measurements are stopped when the elapsed time is about 60 hours.

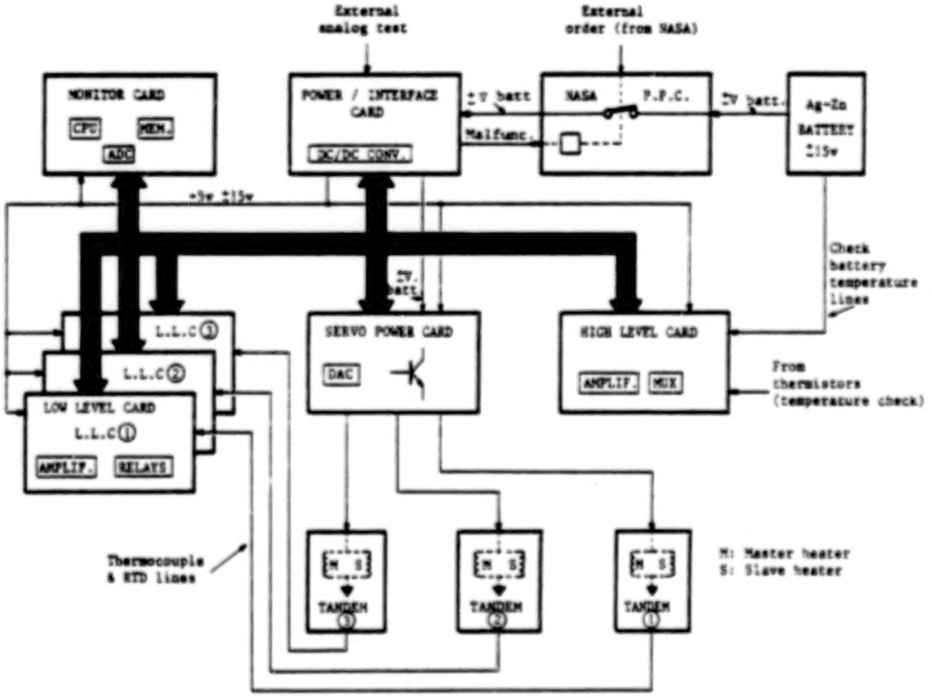

Fig. 3.System block diagram

The program is written with Z-80 assembler language. It includes various subroutines and mainly one called each three minutes to perform the temperature measurements on the working tandem. The power servo-control has a time cycle of 2.8 s and adjust continously the slave heater. These two functions are the primary activities of the microcontroller system and their clock rates have been selected by taking into account the thermal time constants of experimental cells. The program also checks and stores the initial thermal conditions of the whole payload and of the selected tandem at the beginning of each experiment before to apply the power. In a reliability sake we have planned to add some "watch dog" instructions to the program.

Thermal design

Along thermal measurements one important point is the internal temperature value and its stability with time. In a GAS environment it is difficult to obtain long term stability as the Shuttle changes its orientation relative to the sun and the dark sky. Fortunately the canister is well insulated laterally and as we have chosen an insulated top cover with a silverized teflon exterior coating and although the external parts of the container experience wide excursions in temperature, the internal temperatures remain relatively stable. This experimental result was obtained from the analysis of data collected with the Nasa Verification Payload which flight aboard of STS-3 mission (Butler, 1983). From these results we have try to use a simple thermal model for our payload. If we except the case where the Shuttle bay is steadily oriented to the sun and if we take into account the low dissipated power of our payload (close to 10W) we find that the internal temperature is always decreasing with elapsed time. As we measure the thermal conductivity of water (as a standard) we must keep positive temperatures along the experiment duration. We may conclude that this objective is reach with two Shuttle attitudes : bay/earth or passive thermal control (slow rotation along X axis). The importance of the "on" delay in orbit must be emphasized because we benefit from the thermal inertia of the payload.

Testing

A finite element stress analysis of the structure was performed by using NASTRAN program. No resonance frequency below 35 Hz was detected. A serie of environmental tests were performed at Intespace facilities in the end of 1985. They have been conducted on the whole payload secured in a canister similar to the Nasa one.
The thermal tests were carried out in a thermal chamber filled with dry N_2 gas. The temperature was changed up and down from 20°C to 70°C and was cycled from 20°C to - 20°C. The system works correctly in this temperature range. The first vibration tests were performed by using along the three axis sinus vibrations from 5 Hz to 2 kHz (sweep speed 2 oct/mn) with a 0.3 g level. No resonance frequency below 35 Hz was detected. The second tests were carried out by using the Nasa qualification spectra (Nasa, 1984). In this case the vibrations were random with an overall r.m.s. level of 13 g (20 Hz - 2 kHz) and the test duration is specified at 40 s per axis. These tests have proved that the mechanical stiffness of our payload is sufficient and fulfills the Nasa requirements-EMI tests were performed on payload without canister to satisfy Nasa requirements to radiation emission in narrow and broad bands. These measurements were conducted in an anechoic chamber in the frequency range 10 kHz - 10 GHz. The emission level was always below the specifications. To check the ability of G-300 payload in the canister to work correctly in the Shuttle environment we have carried out a radiation susceptibility test. The payload was never disturbed by external elctromagnetic fields simulating Shuttle activities.

Conclusion

G-300 payload is completed and works correctly and environmental tests have demonstrated that it fulfills the Nasa requirements. The safety acceptance is in progress and the last vibration tests are scheduled on the flight model in the beginning of 1987. This payload is essentially the result of the work of paper coauthors and it represents their first step in space research.

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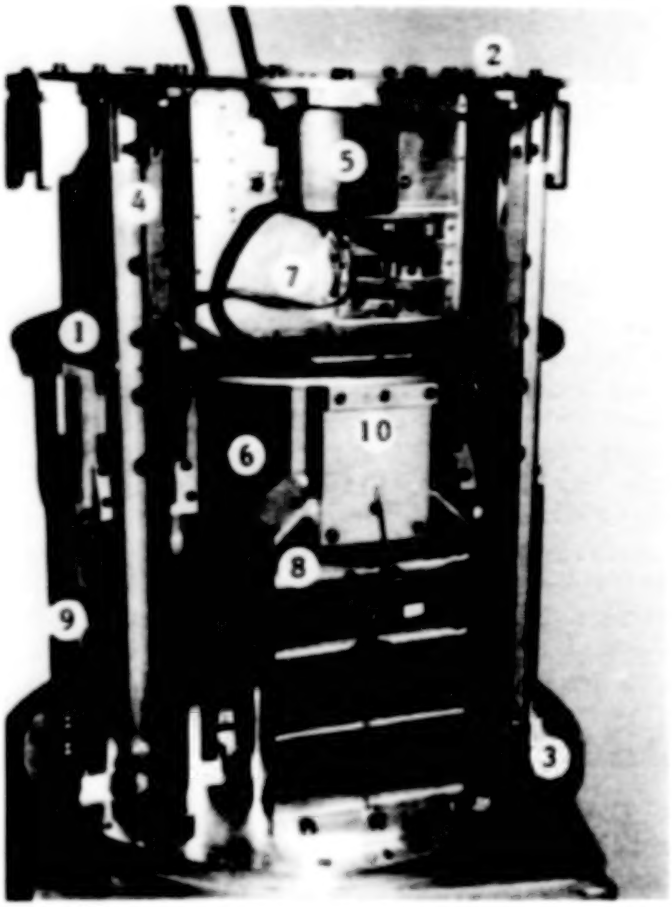

Fig. 4.Photograph of G-300 payload
after integration
1-Intermediate plate
2-Bottom plate
3-Experiment Mounting plate
4-U-shaped strut
5-Bumper
6-Battery box
7-Electronic rack
8-Tandem(two cells)
9-Cell support
10-Fiberglass stiffener

Acknowledgements

The authors would like to gratefully acknowledge :
The Matra Company for giving the opportinity to perform an experiment in microgravity conditions and to reserve a Nasa GAS for this purpose.
The CNES Administration of giving a contract without which this payload cannot be achieved and for providing access to Intespace facilities where the environmental tests were carried out.
Thanks are due to National Semiconductor and Analog Devices Companies for their generous gift of industrial and military grade components and to "Radio" departement of E.S.E. which has performed thick film depositions on heaters.

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RECENT RESULTS FROM MAUS PAYLOADS

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Abstract

Project MAUS is a part of the German material sciences program and provides autonomous payloads for the Space Shuttle. These payloads are housed in canisters which are identical with those of NASA's Get-Away-Special program. The main components of the hardware are: a standard system consisting of power supply, experiment control, data acquisition and the experiment modules containing experiment specific hardware. Up to now, three MAUS modules with experiments from the area of material sciences have been flown as GAS payloads. Results will be reported from GAS Payload Number G-27 and G-28 flown aboard STS-51G.

MAUS Standard System

A MAUS Payload consists of the experiment mounting structure (EMS), the batteries, the standard electronics for experiment control and data acquisition, the house-keeping systems, and the experiment hardware.

The experiment mounting structure is built on an adapter ring, 6 posts and 2 experiment platforms with brackets. Three different batteries are providing power for experiments and electronics. The total capacity of the experiment battery is 1.8 kWh. The data acquisition system consists of a microprocessor controlled multiplexer unit with digital and analog inputs. The data are stored via an intermediate memory on tape. The capacity is 10 Mbits. To allow long measurement phases a data reduction system is provided. A detailed description of the standard service system can be found in Ref. 1, a photo with integrated experiment G-27 is given in Fig. 1.

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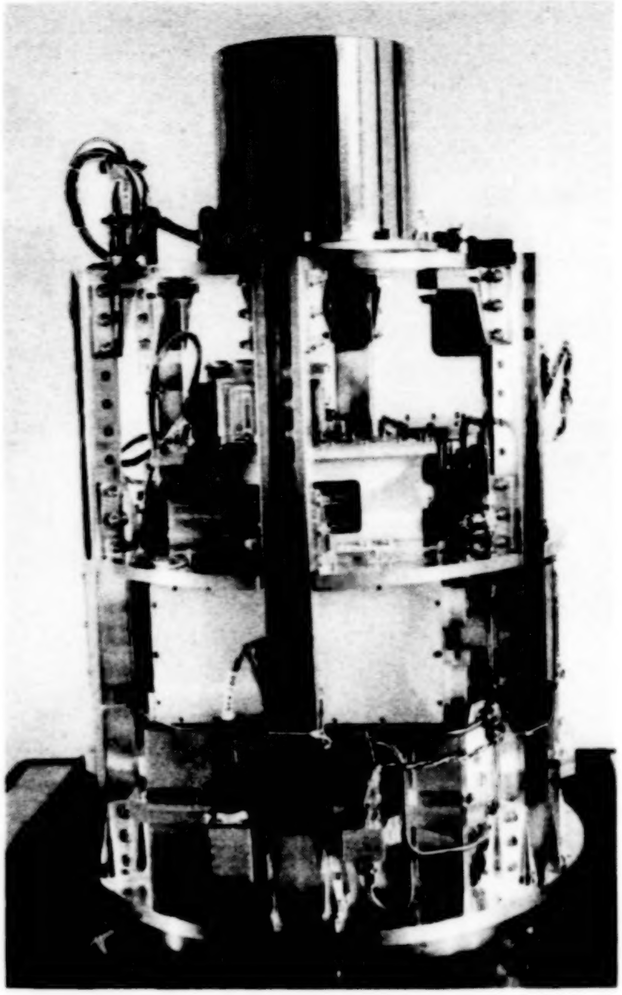

Fig. 1: MAUS standard service system with integrated experiment G-27 on top

Experiment Interface

For experiment accommodation in a MAUS module two platforms are available one of which is adjustable in height by 25 mm-steps. The maximum height for the experiments is 40 mm and the maximum mass about 20 kg. For integration of the experiment dedicated electronics six cards in the standard electronic boxes are available.

Experiments

It is a policy of the project to assign experiments to a MAUS mission rather late in order to maintain a high degree of flexibility. About one year is considered for development of experiment specific flight hardware by the experimenter. Preliminary flight assignments are made from a pool of experiments consisting of microgravity relevant proposals which fit into the limitations set by the MAUS project with regard to powerconsumption, volume, weight etc.. Two GAS Payloads (G-27 and G-28) were flown recently aboard STS-51G as shown in Fig. 2 and a short summary of the results will be given.

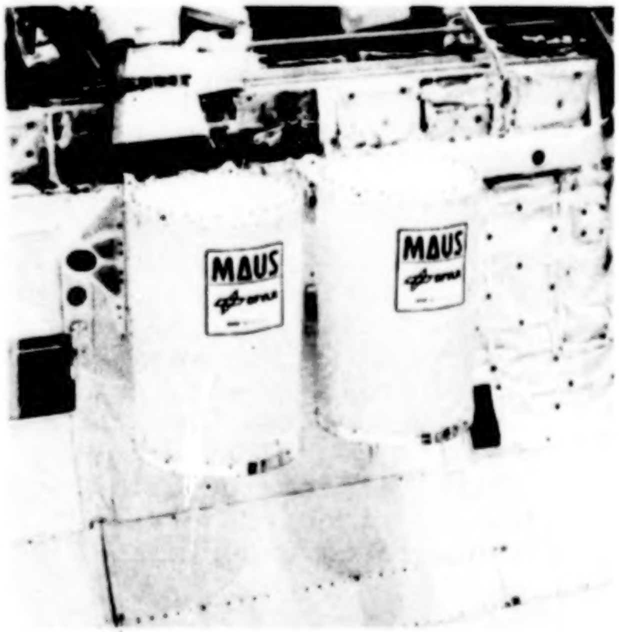

Fig. 2: GAS-payloads G-27 and G-28 in STS-51G cargo bay

"Fundamental Studies in the System Manganese-Bismuth"

Investigator: P. Pant, Krupp Research Institute, Essen

The main objective of this experiment is the synthesis of the intermetallic compound MnBi in an isothermal furnace. The compound forms by a peritectic reaction at 450 °C involving bismuth and solid manganese. This kind of reaction is diffusion controlled and requires a longer time for completion as if both components were in a liquid state. On Earth, such reactions are incomplete when both components exhibit different densities and become separated by sedimentation and buoyancy. The compound MnBi has promising applications as a magnet material because of its high theoretical coercitive strength which so far could not be achieved with ground based specimens.

First experiments on TEXUS (Technology Experiments and Reduced Gravity, a German program using sounding rockets) showed that during melting and solidification separation of the components did not occur and forces promoting segregation, e.g. tension gradients did not become effective. The MnBi-phase in the flight samples was found in form of micron-sized particles uniformly distributed. The small size is thought to be responsible for the good properties of the flight samples compared with the ground based samples.

During the course of this MAUS experiment six MnBi samples with a stoichiometric composition of 50 at % Mn and 50 at % Bi were processed in a four-chamber isothermal furnace. Sequentially, each furnace chamber containing two samples followed a preprogrammed temperature profile of heating and cooling which was exactly executed including the oscillations around the peritectic temperature. During the critical phase of processing the microgravity levels averaged $\pm$ 5 x 10^{-5} g as indicated by the house keeping sensor. The samples obtained do not show any voids or gas bubbles and were safely contained during all phases within the cartridges. There is no evidence of segregation of the components during processing in contrast to the 1-g reference specimens. The flight-samples were investigated by metallography, electron microprobe analysis, x-ray diffraction and magnetic measurements at room temperature and at 4 K. The lattice constants do not deviate from ground based data. However, the amount of MnBi compound formed in the flight samples increased from 18 to 46 %. MnBi regions with a linear extension of about 200 µm can be found at several locations in the sample as shown in the micrographs of Fig. 3. Here the ground based sample is compared with a representative area of the flight sample. Magnetic measurements reveal that the flight samples exhibit about 50 % of the theoretically predicted value of 75 emu/gram. The essential result of this experiment is that the yield of the peritectic reaction is improved during microgravity processing.

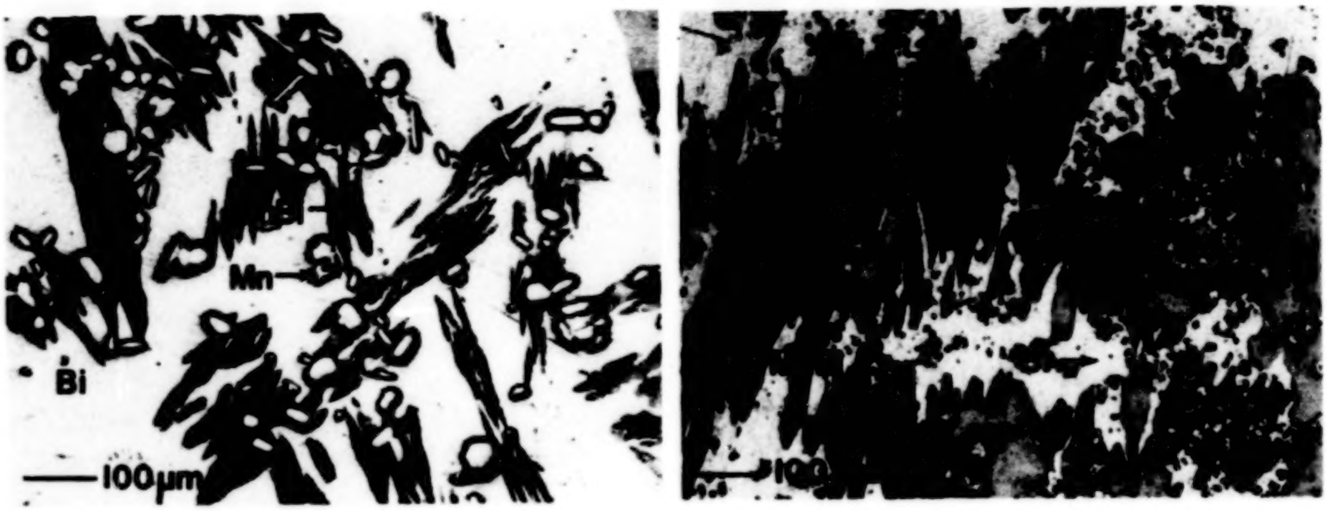

Fig. 3: Micrographs of Mn-Bi samples showing the distribution of Mn, Bi and the compound MnBi. Ground based sample left, flight sample right. MnBi compound is represented with grey color.

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"Slip Casting Under Microgravity Conditions"

Investigator: Dr. K. Schweitzer, Motoren und Turbinen Union (MTU),
München

The processes of slip casting employs a ceramic slurry to form complicated shapes of hollow bodies. On earth, this process is limited in applications because of gravitational influences on the dispersed particles in the slurry. Sedimentation can only be avioded by the use of materials with equal densities or by the utilization of stabilizing additives. However, the latter may be harmful to the desired properties of the slip cast product. Goal of this experiment is to demonstrate with model materials that slip casting is possible in microgravity even with unstabilized suspensions. Using mixtures of powders with different density, grain-size and concentration. For this reason ceramic and/or metal powders are homogenously mixed in solid paraffin by kneading. Rods of these solid slurries are pressed into cartridges against the ends of porous ceramic disks which are mounted in the lower halves of these cartridges.

During weightlessness thirteen samples of these solid slurries were melted by heating the upper part of the cartridges in a furnace. Then the slip casting process was started by additionally heating the lower part of the cartridge containing the suction bodies made of porous ceramic. These did slowly absorb paraffin but not the dispersed particles. The casting process was stopped by turning off the furnace and cooling the samples. Solidification of the paraffin did preserve the slip cast layers as well as the residual slurries for later examination on earth in respect to their structure and particle distribution.

Due to a temperature excess of the upper heater the programmed temperature profile could not be executed properly during the mission. To analyse the impact of this malfunction on the samples the complete furnace including specimens has been examined by means of computer tomography. The slip castings are still under investigation.

The authors would like to thank Dipl.-Ing. P. Pant, Dr. K. Schweitzer and the German Ministry for Research and Technology (BMFT) for providing the quick-look results.

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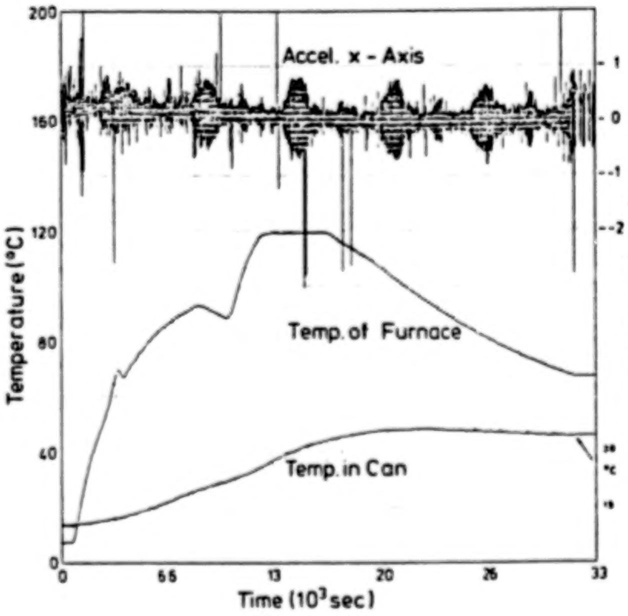
Housekeeping Data

In addition to the experiment also housekeeping data are monitored and recorded during flight by the MAUS standard system, i.e. acceleration data, battery-voltage gas temperature, gas pressure in the MAUS canister as well as in the batteries. All values except acceleration are set to a certain limit. As an example the acceleration data for payload G-27 are reproduced in Fig. 4. It can be recognized that a high degree of g-jitter is present during the 9.3 hours of experiment operations.

Furthermore, housekeeping data can be correlated with the experiment specific data. In Figure 5 the temperature of the furnace is compared with the temperature in the canister. Heat dissipation from the experiment leads to a slow temperature increase of the standard system.

Up to now 10 MAUS payloads have been flown, three of them in the GAS program. The obtained housekeeping data (some of them are presented in Tab. 1) confirm that verification activities during payload preparation resulted in a predicted behaviour of the system. This shows that the MAUS standard system represents a mature technology capable to conduct a large variety of different experiments.



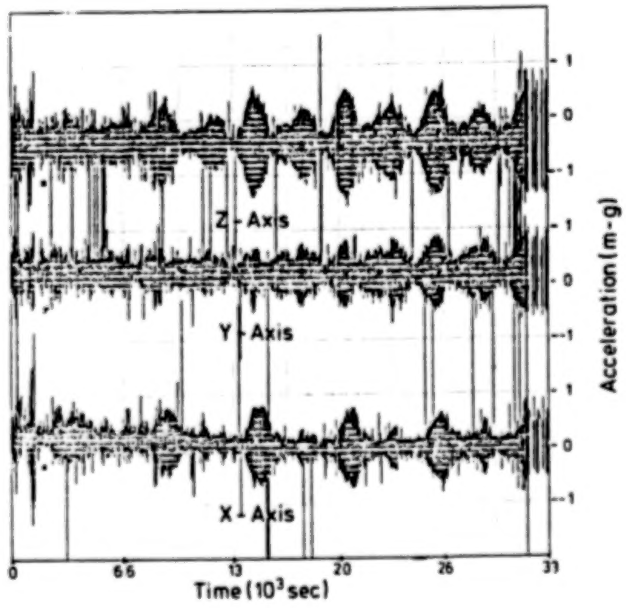


Fig. 5: Correlation of housekeeping data for experiment G-27

Fig. 4: Accelerations in x, y and z axis for experiment G-27

Housekeeping Data

Experiment	Temperature Exp. Start	Temperature Exp. End	Average Power	Experiment Duration
DG-205I	13.4 °C	22.1 °C	17 W	23.9 h
DG-205II	10.6 °C	23.4 °C	17 W	78.5 h
DG-206A	8.8 °C	12.0 °C	78 W	10.0 h
DG-306	12.8 °C	36.2 °C	125 W	5.6 h
DG-315	17.9 °C	49.3 °C	138 W	1.6 h
DG-318	17.4 °C	42.0 °C	275 W	2.8 h
DG-200	10.3 °C	34.3 °C	43 W	9.3 h
DG-206B	7.0 °C	43.5 °C	100 W	9.0 h

Gas temperature at a post close to position of experiment platform

Future Planning

The German MAUS-program will continue with flights of dual payloads using the remaining 22 GAS options. Launch Service Agreement with NASA have been signed. The MAUS standard system is also available by MBB/ERNO on a commercial basis.

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MICROGRAVITY EFFECTS ON ELECTRODEPOSITION OF METALS AND METAL-CERMET MIXTURES

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ABSTRACT

An experimental system, designed to investigate the potential advantages of electrodeposition in microgravity, is being developed by the McDonnell Douglas Astronautics Company - Huntsville Division and the University of Alabama in Huntsville. It is intended to fly as an Orbiter payload when NASA resumes STS operations. The system will provide power, thermal conditioning, command and control for the production of electrodeposits; system performance data will be recorded for post-flight analysis. Plated metal surfaces will be created using simple electrolytic cells with pure metal electrodes immersed in aqueous electrolytic solutions. Crystalline structure and other properties will be analyzed to identify differences between samples produced in flight and those obtained from ground-based operations.

INTRODUCTION

Research in the 1800's resulted in formulation of the basic quantitative relationships for electrochemical reactions involved in electrodeposition (electroplating) and led to the establishment of commercial electroplating processes we know today. Michael Faraday[1] wrote the fundamental laws of electrolysis, which govern electrodeposition, in 1833. Fifty-three years later, a young experimenter named Charles Hall[2] discovered the method for creating pure aluminum using an electrodeposition process. He went on to help found the company which became Alcoa. In 1916, O. P. Watts[3], at the University of Wisconsin, published the time-honored ''Watts Bath'' formula for electroplating nickel. The first commercial process for electrodeposition of chromium emerged in 1924. We all benefit from applications of these developments and the many products which involve electrodeposition.

Now, with the opportunity to experiment in space using NASA's Space

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Transportation System (STS), the effects of reduced gravity (microgravity) on electrodeposition carried out over long periods of time can be studied. Recent research using more limited facilities has shown that electrodeposition in a microgravity environment may hold a key to developing superior metal catalysts and surface coatings with special corrosion resistance and hardness characteristics.

In 1976 Grodzka et al[4] reported interesting results from an experiment performed on NASA's Skylab II Mission. It was found that silver crystals grown by an electrochemical copper displacement process were smaller and more perfect than crystals produced on earth.

Ehrhardt[5] found that nickel electroplated on gold in low gravity was impervious to nitric acid. A nickel deposit was produced during six minutes at approximately 10^{-4}g aboard a British Aircraft Corporation Skylark 7 rocket. Nickel is normally etched by nitric acid. This finding, while not conclusive, indicates that electrodeposition of nickel in microgravity may increase its corrosion resistance.

Riley and Coble[6,7] at the University of Alabama in Huntsville (UAH), used the NASA KC-135 microgravity research aircraft to study the effects of gravity-driven convection currents on electrodeposition. The KC-135 flys parabolic trajectories which provide 10^{-2}g for approximately 25 seconds. Diffusive flow rates for cobalt electrodeposition systems operated at 10^{-2}g appeared to be significantly less than flow rates measured for convectionless systems on earth. It was concluded that additional study is needed to substantiate and fully understand this result.

As a continuation and expansion of work already accomplished at UAH, an experimental system is now under development to be flown as part of the NASA G-105 Get-Away-Special (GAS) payload. MDAC's Huntsville Division, one of the founding members of the NASA sponsored Consortium for Materials Development in Space, centered at UAH, is working with the university to accomplish flight hardware design and development. The flight system will be integrated into the G-105 experiment payload at UAH. The GAS facilty, a canister with five cubic feet available for experiment equipment, will be provided through Huntsville's Alabama Space and Rocket Center. This will be the first in a series of exploratory missions planned over the next five years.

MICROGRAVITY EFFECTS

The advantages of performing electrodeposition in space are as follows:

(1) gravity-driven convection currents in electrolytic solutions will be reduced to a negligible level;

(2) sedimentation of inert particles in electrolytic solutions will be virtually eliminated.

Convection currents, or the lack of them, may have important effects on the formation of crystalline structures in metal electrodeposits. Metal catalysts are used extensively for industrial processes and the efficiency of catalytic activity is a function of crystalline structure. This aspect of microgravity electrodeposition is therefore an important part of the investigation.

The natural (earth gravity) convection currents between a set of electrodes in an electrodeposition system are shown in Figure 1. This picture was made with a laser shadowgraph/schlieren system in an experiment by Riley and Coble[6]. The electrode surfaces are horizontal with respect to the earth's surface. The positive electrode (anode) is located at the top and the negative electrode (cathode) is at the bottom. The ion-rich (heavier) solution at the anode is drifting toward the bottom; ion-depleted (lighter) solution in the vicinity of the cathode is rising toward the top. In clear contrast, no convection currents can be seen in Figure 2 which is a photograph of the same system operating in microgravity (10^{-2}g).

Codeposition is the electrodeposition of metal together with an inert constituent such as chromium carbide. The inerts, also called cermets, used in codeposition processes are in the form of

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particles a few microns in diameter. Codeposition processes are used to produce surface coatings with special abrasive qualities and extra hardness. These processes normally require some means of continuous mixing to keep inert particles from settling out of the electrolytic solution. In microgravity this problem is eliminated. Codeposition will be studied in this experiment with the objective of producing richer, more homogeneous surface coatings.

EXPERIMENT PLAN

Two processes will be studied in the experiment:

(1) electrodeposition of pure metal;
(2) codeposition of metal-cermet mixtures.

The materials listed in Figure 3 will be used. The metals Ag, Pd, Fe, Ni and Co are of special interest with respect to potential improvements in catalytic performance. Ni and Fe will also be assessed for increased corrosion resistance. The cobalt and chromium carbide mixture provides a hard, anti-friction type surface. Nickel and diamond dust are an effective abrasive combination.

Electrodeposition of Silver

The electrodeposition of silver illustrated in Figure 4 exemplifies the process to be used for all of the pure metal systems. The electrodeposition cell, containing a silver anode and a gold-plated copper cathode, is filled with a solution of silver cyanide. Electrochemical reactions (electrolysis) begin in the cell when the circuit is closed, placing voltage across the cell, allowing electrical current to flow through the silver cyanide solution.

At the anode, silver metal is oxidized and silver ions (Ag^+) enter the solution. At the cathode, silver ions combine with electrons (e^-) and are reduced to metal (Ag). The result of this process is the deposition of pure silver on the surface of the cathode.

Codeposition of Nickel and Diamond

The principles of electrodeposition for a pure metal system also apply to

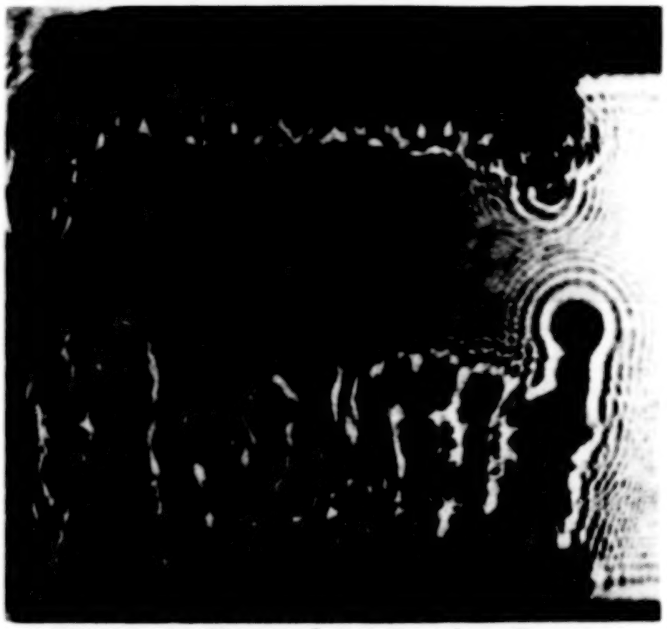

Figure 1. Natural Convection Currents During Electrodeposition

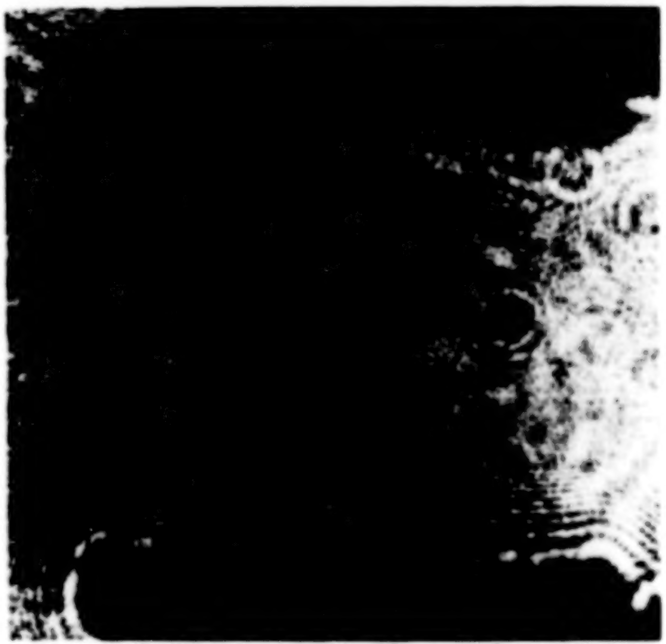

Figure 2. Microgravity Electrodeposition

ANODE METALS
IRON (Fe)
PALLADIUM (Pd)
SILVER (Ag)
COBALT (Co)
NICKEL (Ni)

CODEPOSITION MIXTURES
COBALT + CHROMIUM CARBIDE
NICKEL + DIAMOND DUST

Figure 3. Electrodeposition Materials

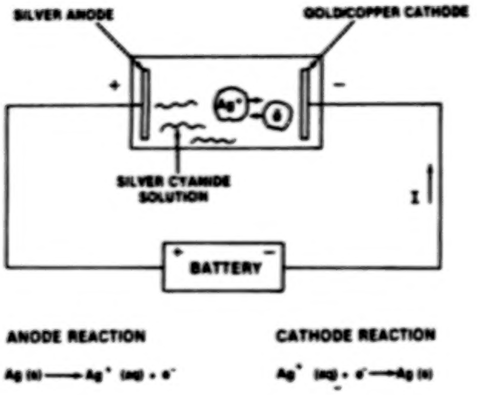

Figure 4. Electrodeposition Cell Concept

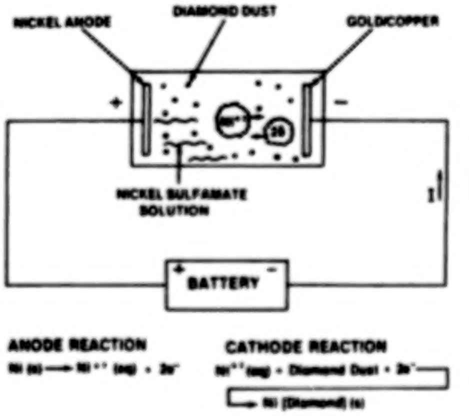
NICKEL ANODE
DIAMOND DUST
GOLD/COPPER
+
−
Ni^{++}
2e
NICKEL SULFAMATE SOLUTION
I
BATTERY
ANODE REACTION
$Ni\,(s) \longrightarrow Ni^{++}\,(aq) + 2e^-$
CATHODE REACTION
$Ni^{++}(aq) + \text{Diamond Dust} + 2e^- \longrightarrow Ni\,(\text{Diamond})\,(s)$

Figure 5. Codeposition Cell Concept

codeposition. Figure 5 illustrates the nickel-diamond dust codeposition cell concept. Here, the minute diamond dust particles (dia. less than 10^{-6}m) are captured along with nickel atoms at the cathode where a solid deposit of nickel and diamond is formed.

Measurements and Analysis

Experiment runs will be made on the ground prior to the flight experiment to obtain data for comparison with microgravity results. The basic measurements for both ground and flight runs are electrodeposition cell current, voltage, temperature and operating time. These variables will be measured and recorded throughout electrodeposition operations. Experiment data will be supplemented with Orbiter provided acceleration measurements and experiment activation/deactivation timing.

Analytical methods will include the following:

(1) Comparison of actual and theoretical cell currents to determine if microgravity processes are completely diffusion controlled, i. e., independent of convection or other effects;
(2) Comparison of electrode surfaces, using scanning electron microscopy to identify differences in crystalline structure;
(3) Analysis of codeposits by surface magnification to determine homogeneity and by decomposition to determine richness of mixture;
(4) Exposure of samples to corrosive environments to determine differences in corrosion resistance.

ELECTRODEPOSITION EXPERIMENT SYSTEM

The system designed for this experiment provides the structures and attachments, power and signal conditioning, data acquisition and thermal conditioning needed for the STS environment and experiment operations. It will be integrated into a GAS payload and installed in the Orbiter payload bay as shown in Figure 6. It occupies one-quarter of the canister and weighs approximately 25 pounds. Power distribution and programmed command and control signals are provided by a control unit located elsewhere in the canister. The control unit is activated via relays in the canister which are operated by a barometric switch during Orbiter ascent and by remote control from the Orbiter aft flight deck during orbital operations. The experiment system contains eight electrodeposition cells which will be operated during a period in the mission when uninterrupted microgravity conditions are expected.

Functional Requirements

The electrodeposition experiment system provides for the following functional requirements:

(1) operation of eight electrodeposition cells and supporting elements for six hours;

(2) sensing of electrodeposition cell current, voltage and temperature;

(3) generation, distribution and display of digital signals for performance measurement;

(4) photographs of cell operation and displays;

(5) distribution of command and control signals from canister control unit;

(6) stirring of codeposition solutions prior to cell operation;

(7) maintenance of 5°C minimum standby temperature and 20°C minimum operating temperature.

Configuration and Operation

The major components of the experiment system are illustrated in Figure 7. The system is mounted on an aluminum base plate which attaches to a GAS canister payload mounting plate. The electrodeposition cell and meter assembly contains the eight electrodeposition cells, ten digital displays, two stirring motors, two heating elements and a strobe light. The cells are polished plexiglass to provide a clear view of the interior. The strobe light, not visible in the illustration, provides back lighting for illumination of the cells.

Prior to electrodeposition operations, the stirring motors run for 20 seconds to mix the inert materials in the codeposition cells. A circular magnet, mounted on the shaft of the motor, spins a tiny bar magnet located inside the codeposition cell. This mixes the solution so that the particles will be evenly distributed throughout the cell before beginning the codeposition process.

The camera is a 35mm Nikon which was

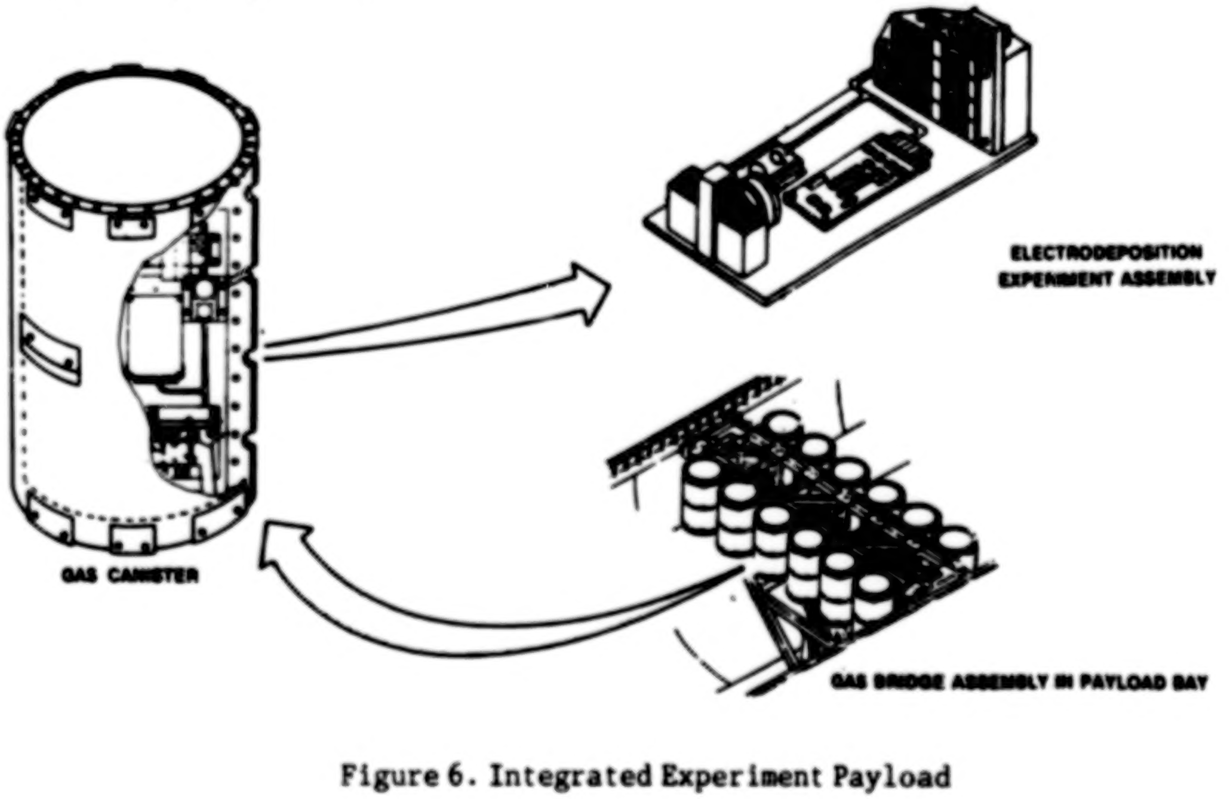

Figure 6. Integrated Experiment Payload

used on an earlier GAS mission. It will photograph the electrodeposition cell and meter assembly 35 times during the experiment. The power/signal conditioning board handles most of the traffic between the canister control unit and the electrodeposition assembly. It provides power inputs for operation of the stirring motors, cells and digital meters. It also generates and distributes digital signals for display and recording of cell performance and temperature.

Cell Assembly

The electrodeposition cells are stacked in two columns of four each. Behind each clear cell face shown in Figure 7 is a cell made up of parts like those illustrated in Figure 8. The cell body is made from a solid piece of plexiglass. On either end of the body a gasket, electrode plate, power connector plate and end cap go together to seal the electrolytic solution reservoir and provide for power input. The holes in the end cap and cell body are for assembly and mounting.

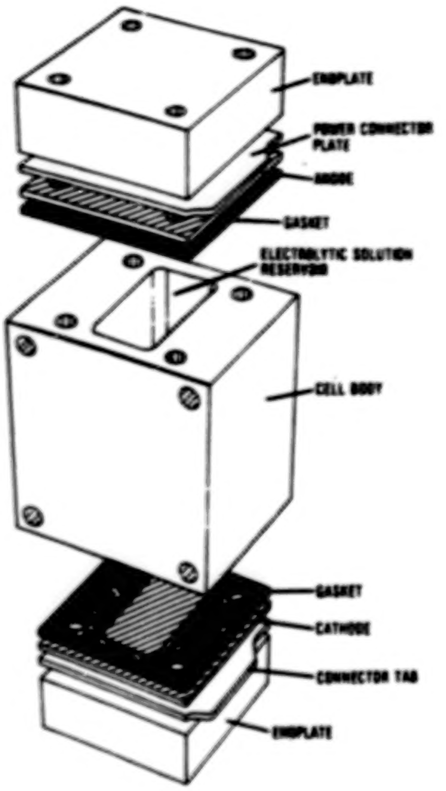

Figure 8. Cell Assembly

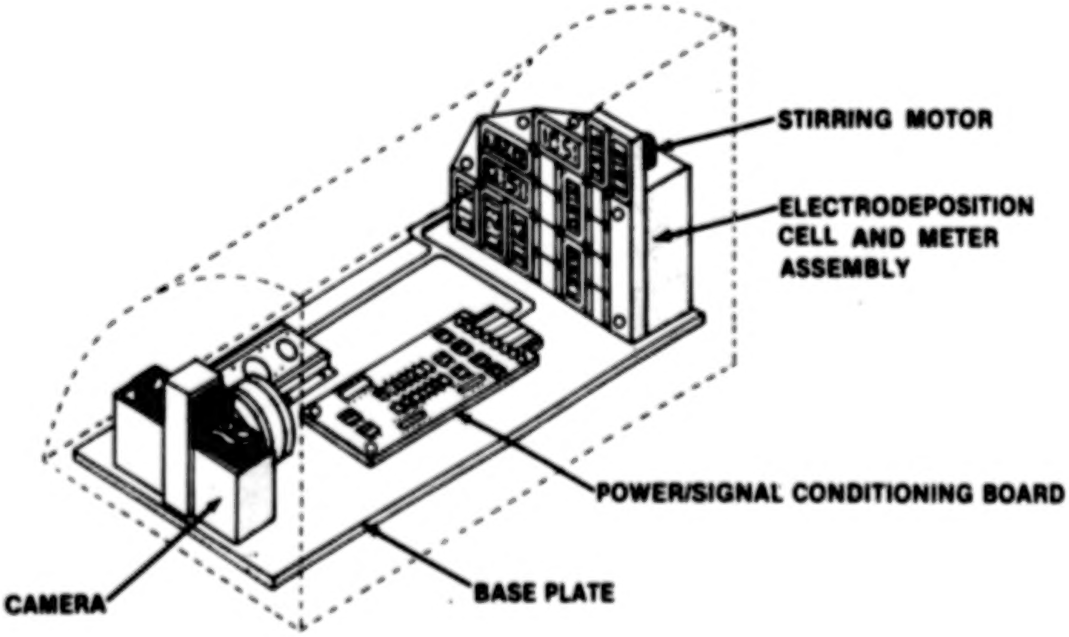
STIRRING MOTOR
ELECTRODEPOSITION CELL AND METER ASSEMBLY
POWER/SIGNAL CONDITIONING BOARD
CAMERA
BASE PLATE

Figure 7. Electrodeposition Experiment Assembly

FLIGHT PLANS

Experiment system-level testing, GAS payload installation and integrated environmental testing are planned for 1986. Environmental testing will include thermal and vibration tests which simulate STS launch and operational conditions. When STS operations are continued and a flight assignment is granted, the payload will be processed as outlined in Figure 9. The payload will be checked out and installed in a flight GAS canister at Kennedy Space Center (KSC). The canister will be mounted in a GAS bridge assembly for installation into the Orbiter payload bay approximately six weeks before launch. Following the mission the payload will be retrieved from the canister, returned to Huntsville and dismantled for analysis.

ACKNOWLEDGEMENT

The MDAC-Huntsville Division Space Station Analytical/Design Engineering, Space Station System Engineering and Integration and Spacelab Engineering organizations are working with the UAH Department of Chemistry and Consortium for Materials Development in Space to develop the electrodeposition experiment flight system. Thanks are extended to all of the many people on the MDAC/UAH team who have contributed to the project.

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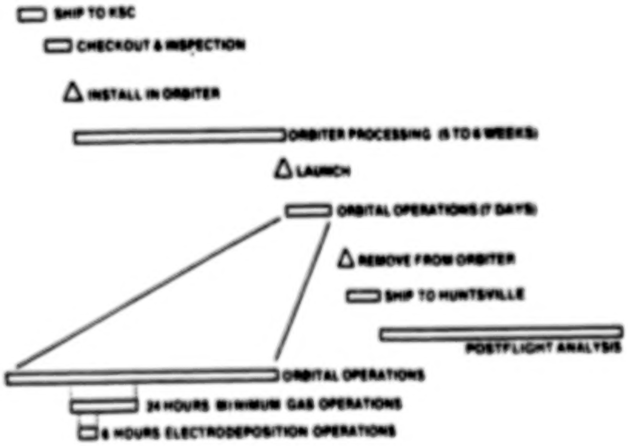

Figure 9. Payload Processing Sequence

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GAS-007: FIRST STEP IN A SERIES OF EXPLORER PAYLOADS

Prepared for the Third GAS Experimenter's Symposium
to be Held at the
NASA Goddard Space Flight Center
Greenbelt, Maryland,
October 7-8, 1986

Written for the Project Explorer Team

by Philip H. Kitchens
Redstone Scientific Information Center

July 28, 1986

ABSTRACT

To date the Alabama Space and Rocket Center (ASRC) in Huntsville has undertaken the sponsorship of three Get Away Specials as part of its Project Explorer program for promotion of space flight and student participation in current space activities. The purpose of this paper is to review the history of Project Explorer, present preliminary experimental results, and describe future ASRC plans for Shuttle Get Away Special payloads, including GAS-105 and GAS-608. The involvement of youth attending the ASRC's SPACE CAMP is also briefly described.

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GAS-007: FIRST STEP IN A SERIES OF EXPLORER PAYLOADS

As part of the NASA Get Away Special program for flying small, self-contained payloads onboard the Space Shuttle, the Alabama Space and Rocket Center (ASRC) in Huntsville has sponsored three of these payloads for its Project Explorer. One of these is GAS-007, which was carried originally on STS mission 41-G in early October 1984. Due to an operational error it was not turned on and was, therefore, subsequently rescheduled and flown on mission 61-C. This paper will review Explorer's history, outline its experiments, present some preliminary experimental results, and describe future ASRC plans for Get Away Special activities, including follow-on Explorers GAS-105 and GAS-608. Additional details on GAS-007 may be found in other papers prepared for this symposium by Chris Rupp, Ed Stluka, Arthur Henderson, and Frank Wessling and also in two earlier symposium proceedings (3,4,5,6).

BACKGROUND

Under the direction of Edward O. Buckbee, ASRC, as the official sponsor, has provided funds for purchase of the GAS-007 payload cannister. From the beginning it has cooperated with two local educational institutions, the University of Alabama in Huntsville (UAH) and Alabama A & M University, in the design, development, assembly, testing, and flight operation of the "can." The Alabama-Mississippi Section of the American Institute of Aeronautics and Astronautics (AIAA) and the Marshall Amateur Radio Club (MARC) have supplied technical support. The universities have furnished laboratory and research facilities. As Explorer has progressed, its manager, Konrad Dannenberg, has interfaced with NASA's Goddard Space Flight Center at major project milestones. Al Orillion has served as liaison to and from AIAA. In addition to these personnel, a number of specialist consultants have provided volunteer-expertise in various subject areas to support the project from its inception through completion of the flight.

As with other Get Away Specials, the Project Explorer payload was conceived and developed around a desire for simplicity and standardization. The container in which it is housed represents the largest of three choices of volume-weight cannisters. Physically it is a cylinder 28.25 inches high and 19.75 inches in diameter which contains a working volume of five cubic feet. GAS-007 met the NASA overall weight requirement for this size can, being under 200 pounds, including experiments and mounting pieces, at the time of shipment.

DESCRIPTION OF PAYLOAD

Explorer carried four experiments in its cannister which were originally formulated by its principal investigators as high school students. Experiment #1 is an investigation in microgravity of solidification of samples of two different alloys. Experiment #2 is a study of the germination and growth of radish seeds in the reduced-gravity environment. The third experiment is an arrangement for electrochemical growth of a complex inorganic crystal. The fourth part of the payload is designated MARCE, as it was prepared by the Marshall Amateur Radio Club (MARC). It represents the first-ever transmission of signals from the Shuttle for reception real-time by amateur radio operators worldwide. Some details of these experiments and their results from STS 61-C are given below.

PROJECT HISTORY

Conceived in 1978, GAS-007 navigated a long road of technical preparation and revision which included a number of changes in its flight schedule. It was subjected to and successfully completed its functional testing phase in the period March 3-16, 1984. In this operation all activities were performed in a laboratory exactly as planned to occur in the actual mission. A SPAR (Space Processing Applications Rocket) battery was utilized. A second major milestone, the system thermal test, was conducted April 7-13, 1984, to simulate the thermal environment expected and to determine any adverse effects on the design configuration. For this test a laboratory power supply was used. The chief result was the discovery that a nutrient pump in the radish growth experiment would freeze at -15 degrees C, and adjustments were consequently made to the heater power outputs for this experiment and for the crystal growth experiment.

The EMI (electromagnetic interference) checkout, conducted June 13, 1984, constituted a third significant test. With MIL-STD-462A as the applicable standard, the assembly was exposed to electromagnetic field radiation over a wide range of frequencies. No problems were found. The final major test barrier, a vibration test, was successfully completed during the period July 18-26, 1984. In this operation the whole assembly was mounted on a large shake table capable of supplying a range of vibration forces. The entire assembly, with its electric power applied for normal transmitter operation, was shaken in three dimensions over a range of acceleration forces. No loose connections were found and the results showed that GAS-007 met the required structural safety margins. Technical data from the vibration and EMI tests and a related stress analysis are given in an earlier paper (5).

The Explorer package was shipped to the Kennedy Space Center in late August 1984. Its checkout and integration into the Shuttle orbiter's bay followed. GAS-007 was carried on the STS 41-G mission by Space Shuttle Columbia, with launch on October 5 and landing at Edwards Air Force Base on October 13, 1984. It was determined, however, only late in the mission that because of an operational error the assembly was not activated as scheduled. Consequently no experimental data were acquired. A careful postflight analysis revealed no evidence of anomalies within the cannister and plans were developed for a reflight on a subsequent Shuttle mission.

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A few minor actions were required for preparation for a new mission. Chief of these was the necessity to replace the main battery due to aging. Of the two SPAR battery spares, one developed a casing leak and the second exhibited low voltage in one cell. Because of the battery difficulties, assignment to mission STS 51-G was abandoned and an SRB (Solid Rocket Booster) battery was selected as a replacement. The new power source had a capacity of 50 amp-hours at 28 volts dc at the the time and therefore provided a greater reserve overall for GAS-007. Fortunately, also, this battery fit into the existing space occupied by its SPAR predecessor. Beside the battery replacement, a change in the MARCE transmitter was made when approval was received to upgrade its radio frequency power from 0.5 to 5.0 watts. Some minor modifications in MARCE software were also made.

On October 20, 1985, GAS-007 was shipped to the Kennedy Space Center for its reflight on STS mission 61-C. Following a period of checkout and integration similar to that for the previous 41-C mission, the 170-pound Explorer was launched on January 12, 1986. Carrying a crew of seven astronaut-pilots, payload specialists, and mission specialists, the Shuttle Columbia placed GAS-007 and ten other cannisters into an orbit 160 nautical miles high of 28.5 degrees inclination.

ORBITAL ACTIVITIES

GAS-007 was turned on, as scheduled by the Crew Activity Plan, at 11:50 (i.e., eleven hours fifty minutes) hours after liftoff. This action was accomplished by a crew member's keying numerical codes into the Autonomous Payload Controller (APC) inside the orbiter, activating two MARCE relays in quick succession and beginning a period of automatic operation. Because other papers planned for this symposium are devoted to some of the experiments on Explorer, the reader is referred to these for more detail.

Experiment #1, involving the solidification of two alloys in reduced gravity, was prepared by Arthur Henderson, a former graduate engineering student at Clarkson College of Technology who received an undergraduate degree at Alabama A & M University and is now a NASA-Marshall employee. In Henderson's experiment small samples of lead-antimony (Pb-Sb) and aluminum-copper (Al-Cu) hypereutectic alloys were heated, in separate furnaces, from ambient temperature to temperatures above the respective eutectic points, temperature-controlled briefly, and then allowed to solidify. A dedicated electronics package provided the appropriate timing, data management, and interfaces with MARCE.

Henderson's general objective was primarily to determine what differences in alloy structure and properties are produced with cooling under microgravity as compared with the Earth-based condition. He also sought to find out (1)whether any nitrides might be formed by leakage of gas into the samples and (2)the special surface effects applicable during solidification. Preliminary results indicate that the experimental design worked quite well, with both samples being heated as planned. The samples cooled, from the end of the temperature-regulation period to the phase-transition point (solid-liquid equilibrium line), at a rate of approximately 11-12 degrees C per minute. Analysis of the data was still underway at the time this paper was being prepared.

Experiment #2 was prepared under the direction of Guy Smith, who took his undergraduate degree at UAH and is currently Research Associate with the Johnson Research Center at the University. His experiment sought to investigate the germination and growth in space of a specie of radish seeds known as Raphanus sativus. Smith's experiment began as planned, with a small pump supplying a nutrient solution to the growth chamber. The chamber was equipped with a heater intended to sustain 20 degrees C. The plant rooting process was initiated and continued for some 79 hours instead of the anticipated 120 hours. The reduction in growth time was caused by a change in mission planning whereby an earlier-than-normal reentry was elected. When the decision to attempt the early landing had been made, a relay command from the APC signaled a second small pump to discharge a buffered formaldehyde solution into the chamber. This action terminated plant growth and preserved the products for analysis on the ground.

The major purpose of this experiment was to evaluate differences in tissue orientation and organization as they occur under microgravity conditions. After the mission had ended and the cannister opened for inspection, it was learned that the seeds had grown normally, producing plants with an outward appearance that resembles those grown on earth. The roots produced average one centimeter in length. Although the chamber was determined to have been significantly cooler than anticipated, this amount of growth is about as would have been expected for that range of temperatures under earth-based conditions. The plants have been sent to a professional laboratory for full analysis, including "embedding" and "sectioning," but data from those examinations have not yet been returned.

Jonathan Lee, an engineer at the BDM Corporation who received undergraduate and graduate engineering degrees from UAH, has been responsible for Experiment #3. His investigation was concerned with the electrochemical growth of single crystals of potassium tetracyanoplatinate hydrate (KCN) in an aqueous solution under the action of a small (1.3-volt dc) potential. Flash photographs were taken as planned every 40 minutes to document the growth process. Lee's chamber was also equipped with an electric-resistance heater, with its control point intended to be 10 degrees C.

The objectives of Experiment #3 were to produce single crystals of KCN; to investigate the governing reaction mechanism, which had is thought to be one involving electron transfer; and hopefully to evaluate the electrical properties of the product as a "linear chain conductor." A postflight inspection revealed that indeed the process performed quite successfully: four fine crystals, averaging about 2 millimeters in length, were formed as a result of the electrochemical action. These products actually represent two periods of growth, the first corresponding to the planned period of 24 hours, and a second, "bonus" period of 10 hours which arose after the first attempt at landing was waved off. Although the crystals are very much smaller than what would be expected for earth-like conditions, the growth process was demonstrated. This position is confirmed with the high quality photographs taken during the mission. The orbital environment was distinctly colder than that anticipated in advance, and this factor is most likely the major cause of the smaller size of the product. The on-off thermal cycling may also have influenced the results. Analysis of the experimental operation is not yet complete but the crystals seem to be too small to permit detailed examination.

The fourth experiment aboard GAS-007 is MARCE, prepared for the Project Explorer by Ed Stluka, an engineer employed with Teledyne Brown Engineering. As briefly mentioned above, MARCE is the first Get Away Special activity to conduct transmission of signals on an amateur radio frequency for reception around the world. Since details about MARCE were scheduled to be presented at this symposium by its principal investigator, only a summary will be given here.

As the electronic hub and lifeblood of the entire payload, MARCE consisted of four major components: an NSC 800 microprocessor, with its central processing unit and associated memory; a transmitter, with its accompanying dipole antenna; an analog-to-digital converter for voice synthesis; and the SRB battery, which served as the centralized payload energy source. Working in conjunction with the other components of GAS-007, MARCE (1)furnished electrical power, (2)provided timing and sequencing control, (3)acquired sensor data (cannister temperature and pressure) and experimental measurements for storage in memory, and (4)downlinked, i.e., transmitted, its data to earth-based "ham" radio operators.

The objectives of MARCE were essentially two-fold: to ensure, as best possible, the successful operation of the other three experiments and also to transmit the status of each to earth-based receivers in a real-time fashion. Operating at a frequency of 435.033 MHz, MARCE transmitted directly to Earth as planned with an effective radiated power of approximately 5.5 watts during three downlink cycles. In the first downlink the transmitter came on once every minute for a duration of 30 seconds; in the second and third downlinks, once every minute for 45 seconds. In some instances it was also possible to transmit the signals initially to the Oscar 10 satellite, which then relayed them to Earth at 145.972 MHz.

All the objectives of MARCE were achieved with great success. As Stluka reports at this symposium, "A total of 1,440 transmissions were programmed...485 messages have been received to date..." Altogether data for some 110 hours of payload operation were acquired and stored into the MARCE memory. Compared to the goal of a minimum of 120 hours, this total represents a 91% success.

When a decision had been made to attempt an early landing, GAS-007 was turned off by an APC relay command. Because of adverse weather at the landing site, the attempt was waved off. MARC then requested a second power-up of GAS-007, which was approved but which, it was later learned, did not lead to an additional (fourth) 8-hour MARCE downlink cycle of data. When a second attempt at landing was made, bad weather again forced a wave-off. As before, another (fifth) 8-hour downlink was requested and granted, leading to actual transmitter operation. A third landing attempt was likewise aborted, but no additional Explorer operation followed. Mission 61-C finally ended with reentry and landing at Edwards Air Force Base on January 18, 1986, after a bit over 6 days 2 hours of flight. After a short delay, the payload was picked up at the Kennedy Space Center and brought back to Huntsville for postflight analyses.

CONCLUSIONS AND RECOMMENDATIONS

All experiments on GAS-007 worked as designed. Only because of an orbiter environment which was substantially colder than planned were the results not more satisfactory in the cases of Experiments #2 and #3. It is not possible to be exactly certain as to how much better growth would have been achieved, but the experimenters for these investigatins strongly believe that better quality products would have been obtained if additional chamber insulation, more powerful heaters, and/or different Earth-orbiter orientations had been available. It is recommended that this experience be incorporated into future experimenter mission thermal requirements, i.e., planning for an environment of, say, 10-30 degrees C instead of 0-20 degrees C. Cooling provisions to control temperature excursions above 30 degrees C are felt to be unnecessary.

FUTURE EXPLORER GAS PAYLOAD

For several years ASRC has been operating the very successful SPACE CAMP program, which updates high school students on space activities, especially Space Shuttle operations, and the purpose of space missions. The Explorer program is intended to provide continued involvement in space activities for interested campers who have graduated from SPACE CAMP and are now back in school. It was decided that creating an opportunity for students to propose, and eventually fly, their own experiment ideas in space would be the best way to accomplish this goal.

It is of great benefit that ASRC has had a long-time working relationship with UAH relating to Get Away Special missions and their preparation. The University has provided invaluable assistance in the design, construction, and testing of the successful GAS-007.

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GAS-105

UAH was recently awarded a "Consortium for Materials Development in Space" agreement from NASA. Since no student proposals by SPACE CAMP attendees were ready for construction and installation at that time, ASRC offered UAH the next cannister, GAS-105, in return for previous cooperation on GAS-007. It was hoped that early flight opportunities for GAS-105 would greatly contribute to the basic knowledge in the area of microgravity sciences which would be made available to future SPACE CAMPers for new proposals.

The Consortium is now designing a series of microgravity experiments for GAS-105 in cooperation with scientists at such industrial organizations as GTE Research Laboratories, Celanese Research Corporation, and McDonnell Douglas Astronautics Corporation--Huntsville Operations. The payload is, therefore, of a commercial nature, but the experimental results will be used in SPACE CAMP classes. Some SPACE CAMP proposers will also have an opportunity to work on these experiments at UAH during their summer vacations and will thus acquire valuable experience for flying their own proposals.

These experiments are of particular interest to ASRC since they examine and test physical and chemical phenomena in space. They are, therefore, in contrast to the life sciences-oriented proposals normally submitted by SPACE CAMPers as a result of their high school backgrounds. The GAS-105 proposals are very difficult to perform in the highly restricted cannister . This payload demonstrates that many different space experiments are possible in the fields of physics and chemistry. ASRC expects that some of the equipment being developed will be useful, with slight modification as appropriate, for follow-on experiments by SPACE CAMPers.

GAS-608

This package consists of experiments proposed by SPACE CAMPers. Most will utilize space microgravity for the study of biological specimens but one will be devoted to crystal growth. Experiment #1, by Bryan D. Agran, will carry fertilized insect eggs for study on orbit. Comparison tests with identical life forms will be conducted on the ground under conditions as nearly similar as possible to those of space. Insect eggs have been chosen because of their availability, ruggedness, and small size. Experiment #2, by Jay S. Andrews, was originally planned to study the germination of bean seeds in microgravity. He is considering a change to radish seeds due to their faster response to the proper growth conditions.

Experiment #3, developed by Greg T. DeLory will investigate the effect of low gravity on the growth of yeast. One half of his test tubes will contain samples of yeast that grow mitotically (i.e., by budding); the other half, samples that grow meiotically

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(i.e., by producing spores). The test tubes will contain a fiber optic light source probe and photocell so that the concentration of yeast cells in solution can be determined in flight. The tubes will also carry small carbon dioxide, oxygen, and pH sensors. Experiment #4, by Tom P. Malone, is a study of the morphology of a species of phototropic bacteria grown in microgravity. Flight results will be compared with a control sample grown in full Earth gravity. Colonial morphology will be observed and recorded directly in space by means of a 35-mm camera. Individual and small-group morphology will be observed and recorded under the microscope once the bacteria have been brought back to Earth.

Experiment #5, prepared by Jawahar Nayak, will produce the antibiotic streptomycin. Incubation of the organism will occur in liquid media for 48 hours. A sterile environment and a temperature of 25 degrees C will be maintained for optimum growth. The output of streptomycin is to be compared with that for samples grown similarly on the ground. Experiment #6, by Seth A. Watkins will study the growth of silicon and/or gallium arsenide crystals in space and their production potential.

Consideration is also being given to a reflight of Jonathan Lee's GAS-007 crystal growth experiment in order to obtain results under more a closely controlled thermal environment. Several minor changes would be incorporated toward this end by Raymond Cronise in cooperation with Lee.

The Marshall Amateur Radio Club will again provide an SR2 battery as a power source for all experiments and will arrange for all data acquisition and management functions. All experimental requirements will be integrated with MARC-furnished equipment by local members of the L-5 Society. This support to ASRC is provided under the technical direction of Jan Bijvoet, formerly a representative of the European Space Agency and now employed by UAH and working for the Consortium. This activity is an excellent example of broad citizen involvement in future space developments and will lead to better understanding of associated problems as well as potential benefits to all mankind.

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IN SITU OBSERVATION OF MONO-MOLECULAR GROWTH STEPS ON AQUEOUS SOLUTION GROWN CRYSTALS AND THE TRANSPORT OF MOLECULES TO THE CRYSTALS

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Direct in situ observation of mono-molecular growth steps on a crystal growing in an aqueous solution became possible. Combination of this method with high resolution Schlieren method or interferometry, growth mechanism of crystals can be investigated directly. Since observation of growth steps on crystals is the most direct and sensitive way for investigating a crystal growth mechanism, it would contribute to reveal fundamental differnces between the growthin space and on earth. The method was recently extended to in situ observation of the growth processes at high temperatures (1800K).

1. INTRODUCTION

Crystal growth takes place when molecules are integrated to a crystal at the surface via transport of molecules from the bulk solution to the crystal surface. It is therefore necessary to investigate both transport phenomena of molecules by, for instance, diffusion and the integration of molecules at the surface, if one wants to understand the crystal growth mechanism from a fundamental point of view. The former investigation has been performed even before the beginning of this century, leading to development of the Fick's law for the interpretation of growth rate and theories on morphological stability of a crystal. This kind of investigation has been carried out in some space experiments, and, of course, on earth. However up to now there is no plan to investigate crystal growth kinetics at the surface in space. It is very important to investigate the movement of molecular growth steps in space in absence of hydrodynamic perturbations because the movement of the steps and the shape of the steps reflect the growth mechanism in a very sensitive way.

It migh have been considered to be impossible or very difficult to observe such thin steps with the height of less than 1nm during the growth of crystals. However thanks to recent developments on in situ surface observation techniques, one can see the moving mono-molecular growth steps on a TV monitor. It is here proposed to employ in situ observation system for the investigation of crystal growth mechanism in space with the combination of Schlieren method or interferometry to visualize the transport phenomena of molecules to the surface. On earth crystal growth is enhanced due to the presence of convection flows near the surface, otherwise good mixture of the solution near the surface cannot be obtained, leading to unstable growth or inhomogeneous crystals. It is also expected that the absence of convection would lead to a complex growth behavior especially at very low supersaturations because presence of small concentrations of impurity would easily stop the movement of growth steps in space. This kind of complex behavior cannot be predicted exactly from theories. Therefore it would be fruitful to compare the surface of crystals grown in space and on earth by sensitive in situ surface observation techniques.

2. BRIEF HISTORY ON SURFACE OBSERVATION

The growth mechanism of a crystal in an aqueous solution is one of the topics in which scientist are now interested in. Already in 1930 scientist theoretically knew that crystal growth proceeds by pilling up of molecular growth steps which laterally move on a surface. An important theory was put forward in 1949 by Frank [1], namely the spiral growth theory. After the development of the theory, the first spiral was observed in 1951 on a natural beryl crystal and many examples have been reported thereafter. However it was not easy to observe mono-molecular growth steps on crystals like NaCl or K-Alum grown from an aqueous solution. This is because the surface cannot be easily separated from the mother solution without destroying the original surface pattern.

Another experimental method has been applied to verify the proposed spiral growth theory. The growth rate of a crystal was measured at very low supersaturation (less than 1%). This relation is determined by the growth mechanisms. Bennema [2] measured the growth rate of crystals versus supersaturation in aqueous solution and showed that this could be explaned by spiral growth theory.

In 1972 observation of spirals was reported on NaCl grown from an aqueous solution [3] by applying suitable surface treatments and very sensitive optical phase contrast microscopy. Up to now many crystals were found to grow by a spiral growth mechanism through careful surface observation [4]. However it was found that both experimental results were not always consistent. So a new experimental method was required. It was Tsukamoto who showed that direct in situ observation of mono-molecular growth steps on a crystal in a well controlled queous solution is possible and thus coupling the in situ surface observation with kinetic measurements, like growth rate measurements enabled us not only to investigate actual growth mechanisms more precisely but also to find new phenomena which have not been taken into account for the interpretation of crystal growth processes [5].

This in situ observation was started to observe a crystal surface but later high resolution Schlieren method and Mach-Zehender interferometry were added to the system, so that one can see how molecules (growth units) are trasported to the crystal surface. This was further developed recently so that one can employ this in situ observation method to the growth of crystals even at high temperatures, < 1800K, which is now being employed for some oxide crystals grown from high temperature solutions or melts.

In this paper only the principle of the observatin and some of the results will be shown. It may be noted that proto-types of the in situ observation system for both aqueous solution growth and high temperature growth for GAS experiments are already constructed, which show even better resolution than the system which we are now employing in our laboratory, though the size and the weight are much smaller.

3. OBSERVATION METHOD

In order to obtain the image of growth steps on a crystal growing in an aqueous solution, either phase contrast microscopy or differential interference contrast microscopy is employed. Both types of microscopy can reveal very thin growth steps of a few Å. Depending upon the purpose, either transmission or reflection type microscopy can be chosen.

By these microscopies the invisible phase difference arising from the adjacent steps with different level can be converted into visible intensity difference. The optical images are stored on video tapes after some image processings, fig.1 [5,6].

Although these microscopes have been known to be powerful for surface observations, a serous problem arises when one wants to carry out in situ observations, namely the sharp increase of optical aberration due to the fact that the surface of a crystal is observed through a thick solution and glass windows. Our high resolution in situ observation was derived from the success in suppresing large optical aberration by designing new optical systems. The importance of suppressing optical aberration is as an example shown in fig.2, in which the thickness of the solution is 10mm. One cannot see even the shape of the small crystals attached on the side faces of the seed crystal if optical aberration appears. The same principle is applied to the other optics, such as Schlieren method or laser scattering methods.

4. PRESENT PROBLEMS

Our in situ observation system for aqueous solution growth has been applied to solve the following problems, for instance, fig.3.

(1) growth rate of crystals grown in aqueous solution, which is not proportional to the concentration gradient towards the surface

(2) relation between the hydrodynamics of the solution just near the surface and the growth rate or the perfection of the crystal

(3) structure of solution with the combination of laser scattering techniques, in which clustering of molecules is already found in supersaturated solution before nucleation

(4) development of a high density liquid layer (less than 100 micron thick) in a diffusion boundary layer (about 400 micron thick), which is closely related to the birth of secondary nuclei in the solution

(5) the relation between the structure of a solution and the structure or perfection of the crystal

5. CONCLUSION

In situ observation, especially surface observation, is very powerful method to detect slight change of growth mechanism or growth conditions in a short time and therefore is concluded to be very useful for the growth experiments in microgravity, fig.4 and fig.5.

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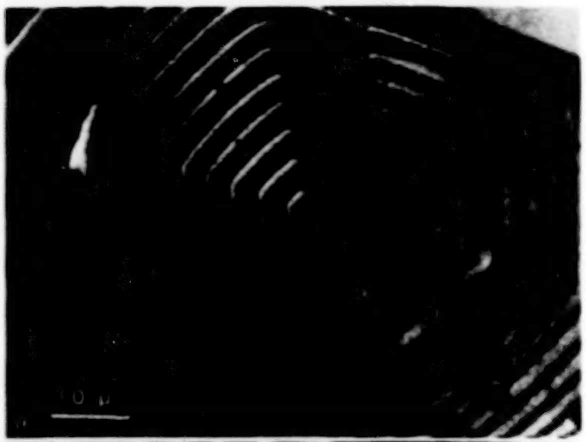


fig.1

Spiral growth steps on CdI_2, taken by differential interference contrast microscopy, photographed from a TV monitor, in situ

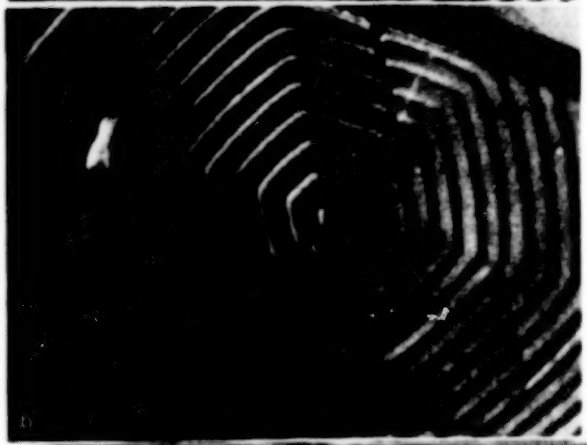
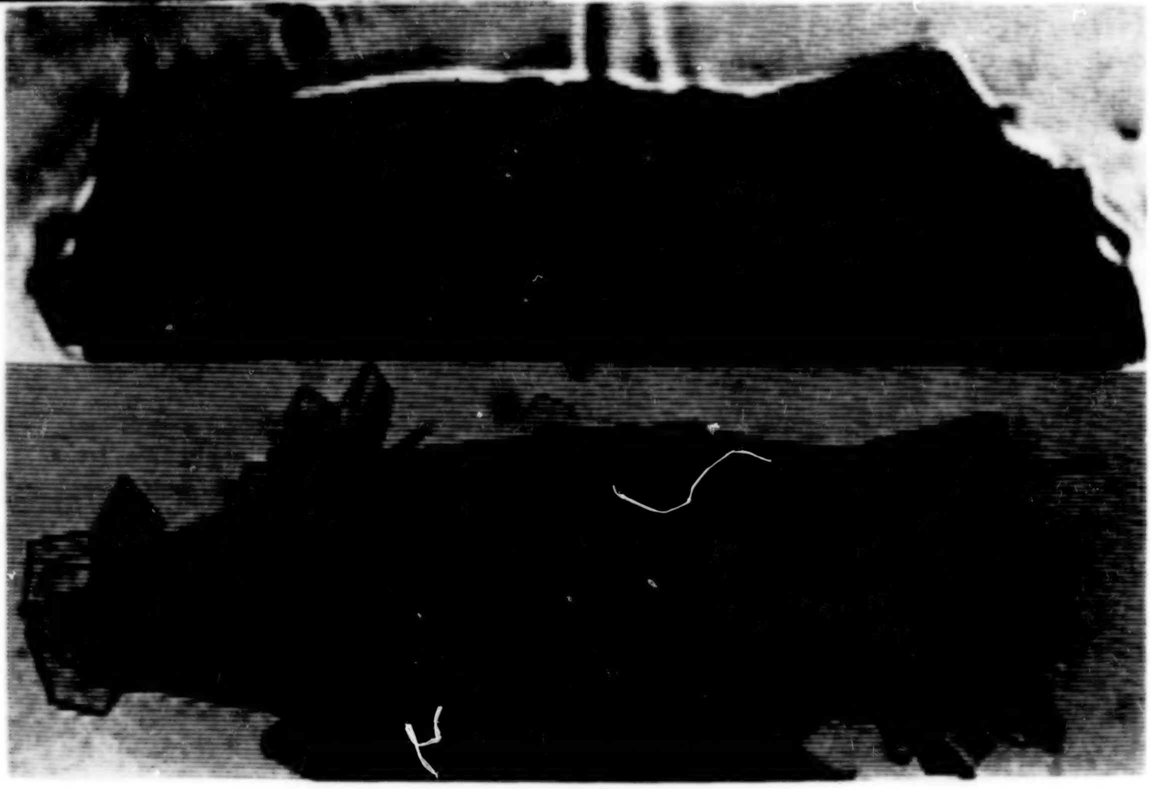


fig.2

Improvement of optical images by suppressing the optical aberration due to the thickness of the solution (10mm) in the optical path



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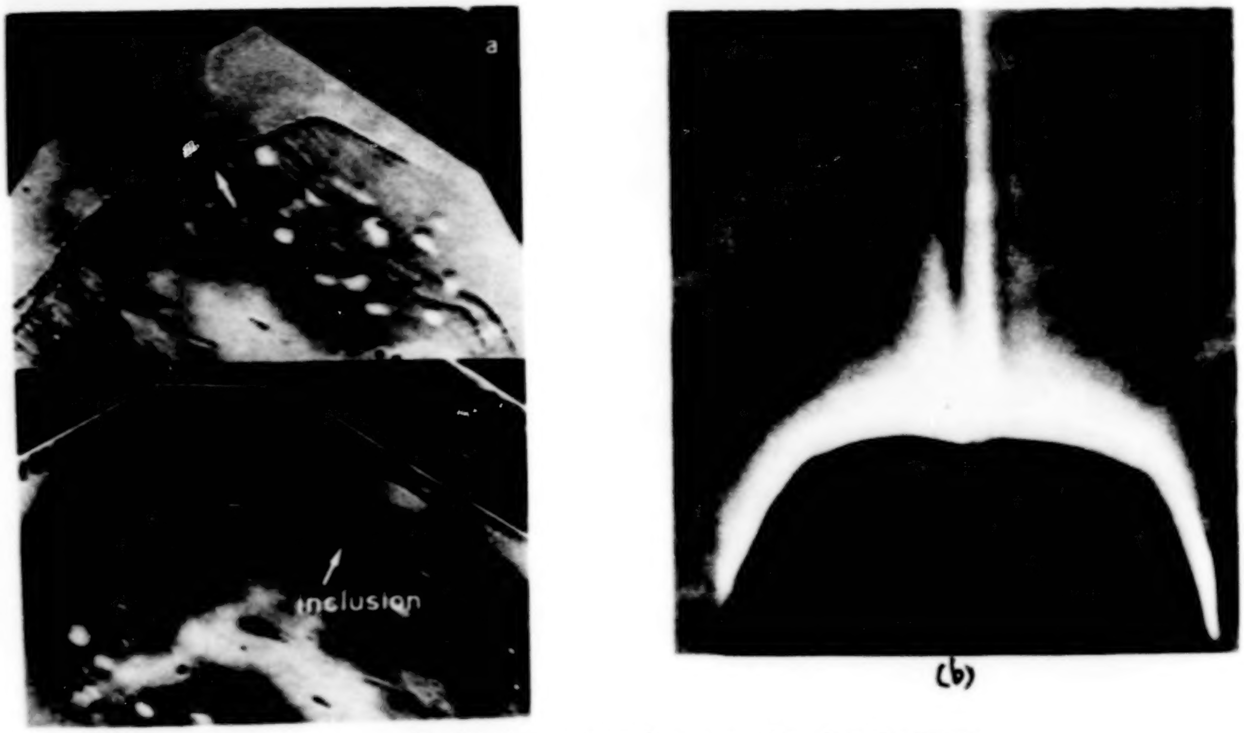

fig.3 Inclusion trap due to the development of a convection plum, when the supersaturation is above 0.5%, (a) surface micrograph and (b) Schlieren image

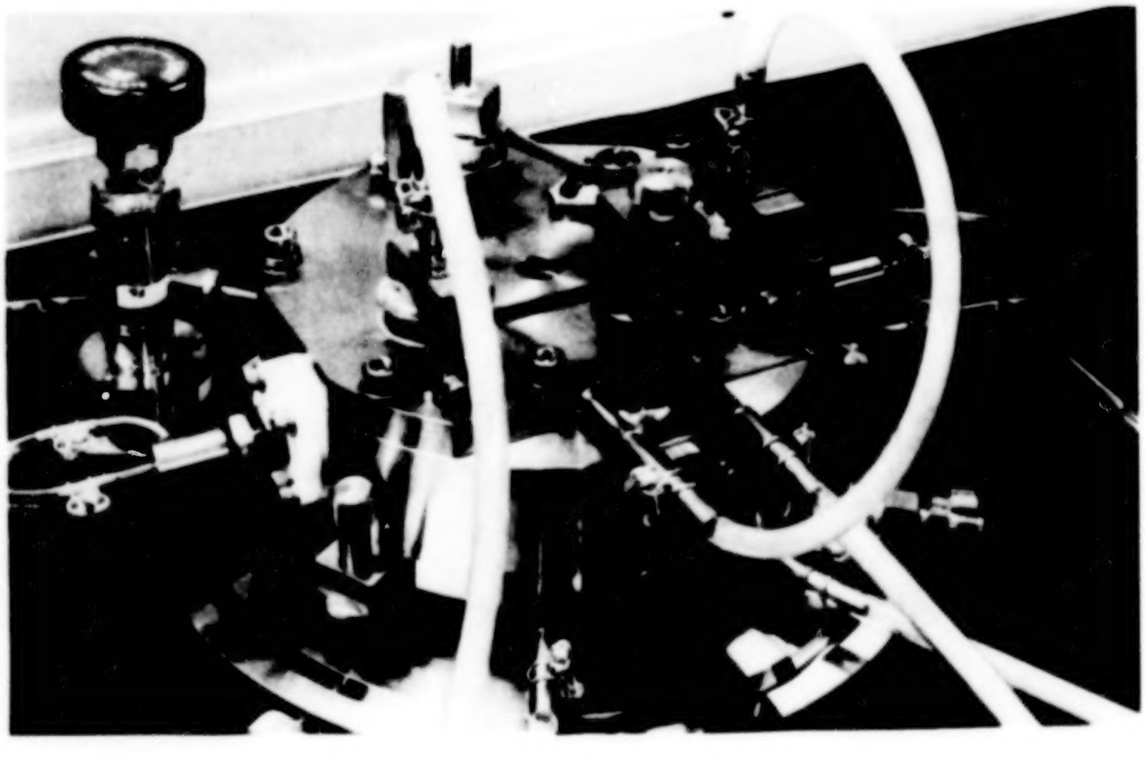

fig.4 (a)

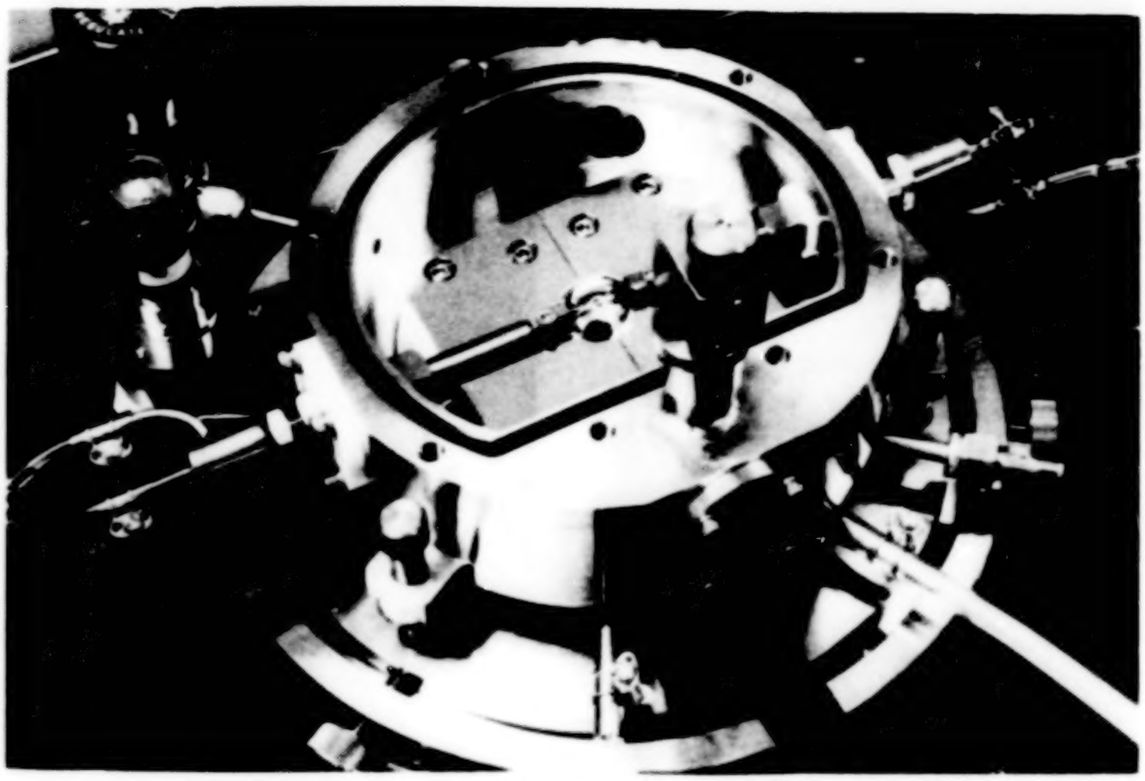

fig.4 Proto-type growth cell at high temperature (1800K) for in situ observation, (a) outside view and (b) the inside, 15cm in diameter

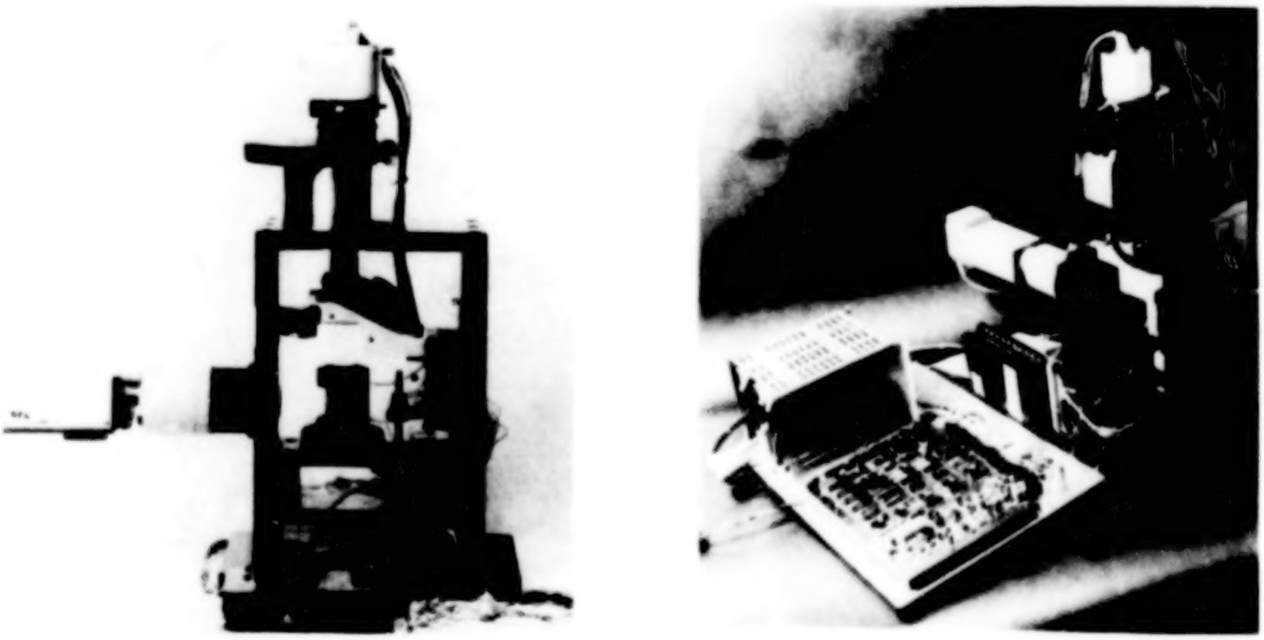

fig.5 Proto-type microscope in microgravity, by which one can observe growth steps with mono-molecular height and automatically measure the growth rate of a crystal

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16. Abstract

The 1986 Get Away Special (GAS) Experimenter's Symposium will provide a formal opportunity for GAS Experimenter's to share the results of their projects. The focus of this symposium is on payloads that have been flown on Shuttle missions, and on GAS payloads that will be flown in the future.

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